SITE: Florida Smelting- Buffaloo
BREAK: 1.8
OTHER: v.8

T N & Associates, Inc.
Engineering and Science

September 30, 2005

Mr. William Joyner
Remedial Project Manager
U.S. Environmental Protection Agency
61 Forsyth Street, SW 11th Floor
Atlanta, Georgia 30303

Subject: Florida Smelter Company – Buffalo Avenue
Preliminary Assessment/Site Inspection Final Report
EPA ID No. FLN000407555
EPA Contract No. 68-S4-01-01 (STAT 4)
Task Order No. 0016

Dear Mr. Joyner:

The T N & Associates, Inc. (TN&A) Superfund Technical Assessment Team (STAT) is submitting the report, CERCLA Eligibility form, original topographic map, references cited, scoresheets, and confidential pages for the Florida Smelter Company - Buffalo Avenue site (FSC Buffalo) in Jacksonville, Duval County, Florida.

Please contact me at 678-355-5550 extension 5704 if you have any questions or comments regarding this report.

Sincerely,

Gregory J. Kowalski
STAT Program Manager

Enclosure

CC: Fran Harrell, EPA Contracting Officer (w/o enclosure)
Mike Norman, EPA Task Order Project Officer (w/o enclosure)

10762859

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PRELIMINARY ASSESSMENT/SITE INSPECTION REPORT

FLORIDA SMELTING COMPANY / BUFFALO AVENUE
JACKSONVILLE, DUVAL COUNTY, FLORIDA

U.S. EPA ID No. FLN000407555

Revision 0

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region 4
61 Forsyth Street
Atlanta, Georgia 30303

Prepared by:

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Contract No.	:	68-S4-01-01
Task Order No.	:	0016
Date Submitted	:	September 30, 2005
EPA Task Monitor	:	William Joyner
Telephone No.	:	404-562-8795
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CERCLA Eligibility Form

Site Name: Florida Smelting Company/Buffalo Avenue Site

City/County/State: Jacksonville, Duval County, Florida

EPA ID Number: FLN000407555

Type of Facility: ____ Generator ____ Transporter ____ Disposal
____ Treatment ____ Storage (> 90 days) X Former Smelter

	Yes	**No**
Has this facility treated, stored, or disposed of a RCRA hazardous waste since Nov. 19, 1980?		X
Has a RCRA Facility Assessment (RFA) been performed on this site?		X
Does the facility have a RCRA operating or post-closure permit? If so, date issued:		X
Did the facility file a RCRA Part A application?		X
If so:		
1) Does the facility currently have interim status?		
2) Did the facility withdraw its interim status?		
3) Is the facility a known or possible protective filer?		
Is the facility a late (after Nov. 19, 1980) or non-filer that has been identified by EPA or the State?		X
Is the site a Federal Facility?		X
Is there at least one source on site, which is not covered by CERCLA Petroleum Exclusion Legislation?	X	
Is the facility owned by an entity that has filed for bankruptcy under Federal or State laws?		X
Has the facility lost authorization to operate or had its interim status revoked?		X
Has the facility been involved in any other RCRA enforcement action?		X

CONTENTS

APPENDICIES

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has tasked the T N & Associates, Inc., (TN&A) Superfund Technical Assessment Team (STAT) to perform a Preliminary Assessment/Site Inspection (PA/SI) under Contract Number (No.) 68-S4-01-01 at the Florida Smelting Company/Buffalo Avenue (FSC Buffalo) site, EPA Identification (ID) No. FLN000407555, located in Jacksonville, Duval County, Florida.

The primary objective of a PA/SI is to determine whether a site has the potential to be placed on the National Priorities List (NPL). The NPL identifies sites at which a release, or potential release, of hazardous substances poses a serious enough risk to the public health or the environment to warrant further investigation and possible remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and the Superfund Amendments and Reauthorization Act of 1986.

Information gathered during the PA/SI is used to generate a Hazard Ranking System (HRS) score. The HRS score is the primary criterion EPA uses to determine whether a site should be placed on the NPL. Generally, PA/SIs are conducted at sites where sampling is necessary to fulfill HRS documentation requirements or determine whether a site may be removed from the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), the CERCLA Information System database. CERCLIS no longer includes sites that EPA has assessed and designated as "No Further Remedial Action Planned", or archive, sites. An archive designation means that, to the best of EPA's knowledge, the Superfund has completed its assessment and determined that no further steps will be taken to list this site on the NPL; however, an archive site is subject to future listing if subsequent information indicates this decision was inappropriate or otherwise incorrect. An archive decision does not necessarily mean that a given site is free of associated hazard; it means only that the location is not considered a potential NPL site based on available information.

Specifically, the objectives of this PA/SI are to accomplish the following:

- Obtain, review, and summarize relevant file material
- Document current site conditions
- Collect samples to determine the nature and extent of contamination
- Collect samples to establish representative background levels
- Identify and summarize human and ecological target populations
- Evaluate groundwater and soil exposure pathways

This report documents findings of the fieldwork conducted during the week of June 13, 2005, at the FSC Buffalo site. EPA Region 4 and the Florida Department of Environmental Protection (FDEP) provided the historical information and file documentation used within this report.

2.0 SITE BACKGROUND

This section describes the site and its present and past operations, waste disposal practices, regulatory history, previous investigations, and potential source areas.

2.1 SITE DESCRIPTION

Limited historical information exists for the FSC Buffalo site. The site was identified in a study of former lead smelting facilities that was published in the *American Journal of Public Health* and reported by ABC News (Refs. 1, 2). The study identified approximately 430 former lead smelting sites that may contain potentially hazardous soil lead levels and are "unrecognized in the United States" (Ref. 3). The Florida Smelting Company (FSC) located at 5800 Buffalo Avenue in Jacksonville, Florida, is listed as one of the sites (see Figures 1 and 2) (Refs. 1, p. 4; 4).

According to the EPA Site Determination, FSC began operations at the Buffalo Avenue location in 1950 and continued until around 1960 (Ref. 3). The geographic coordinates provided in the Site Determination are 30° 22' 38" north latitude and 81° 38' 27" west longitude (Ref. 4). The building is no longer present at this location and it is unclear what types of smelting operations (if any) were performed at the facility (Ref. 3). The Site Determination concluded that the large number of potential nearby targets and the limited information about the site justified the site for inclusion into the CERCLIS database, and recommended a Preliminary Assessment (Ref. 3).

The former FSC location is believed to exist primarily on a Seaboard Coastline Railroad Company (Seaboard) parcel of property, adjacent to the northwest corner of a bulk fuel depot owned by Support Terminals Operating Partnership LP (Refs. 5, 6). Seaboard is owned by CSX Transportation, Inc. (CSX). All subsequent references to the property will list CSX as the property owner.

2.2 ENVIRONMENTAL SETTING

The Jacksonville area is characterized by minimal topographic relief with elevations with ranging from mean sea level (msl) at the St. Johns River, to 25 feet above msl to the west. The site elevation is approximately 12 feet above msl (Ref. 4). The tidal St. Johns River is located 0.35 mile east of site and is considered the probable point of entry. The St Johns River flows to the north and east for approximately 12 miles then enters the Atlantic Ocean (Ref. 4). The site exists amongst numerous bulk fuel depot facilities and residential areas exist 0.25 mile to the north and south of site (Refs. 4, 5, 6).

The climate in Jacksonville is characterized by mild winters and warm summers. Weather records from the Southeast Regional Climate Center list the average annual temperature as 68.7°F. January is the coldest month, averaging 53.8°F, and July is the warmest, averaging 82.4°F (Ref. 7). Rainfall averages 52.39 inches per year (Ref. 7). The mean annual lake evaporation in the area is 45 inches per year, yielding an annual net precipitation of 6.3 inches (Ref. 8, p. 4). The 2-year 24-hour rainfall event for the area is approximately 5 inches (Ref. 9).

2.3 SITE OPERATIONS AND REGULATORY HISTORY

According to the EPA Site Determination, FSC began operations at the Buffalo Avenue location in 1950 and continued until around 1960 (Ref. 3). The building is no longer present at this location and it is unclear what types of smelting operations were performed at the facility (Ref. 3). The site currently exists on a CSX parcel of property, immediately adjacent to the northwest corner of a bulk fuel depot owned by Support Terminals Operating Partnership LP (Refs. 5, 6). Waste storage and disposal practices during smelting operations are unknown. The smelting process is a major source of lead fume emissions (Ref. 10).

No site-specific regulatory or release history has been identified. The site was identified in a study of former lead smelting facilities that was published in the *American Journal of Public Health* and reported by ABC News. The study identified approximately 430 former lead smelting sites that may contain potentially hazardous soil lead levels and are "unrecognized in the United States" (Refs. 1, 2). No environmental sampling has occurred on or near site prior to the current investigation.

2.4 PREVIOUS RELEASES AND INVESTIGATIONS

No investigations have been performed at this location prior to the current investigation.

2.5 POTENTIAL SOURCE AREAS

The EPA Site Determination states that FSC began operations at the Buffalo Avenue location in 1950 and continued until around 1960 (Ref. 3). The smelting process is a major source of lead fume emissions (Ref. 10). No smelting structures are currently on site. A tank farm, unrelated to the FSC Buffalo site, currently exists within 100 feet to the southeast of the former FSC location (Refs. 5, 6, 11). Based on sampling resulted, the potential source area at FSC Buffalo is contaminated soil in the southern-most part of the former building location, south of the railroad tracks. Section 4.0 details the analytical results from samples collected on site.

3.0 SITE INVESTIGATION ACTIVITIES

This section outlines the observations and activities performed by TN&A at FSC Buffalo during the field sampling event conducted the week of June 15, 2005. Individual subsections address the sampling investigation and rationales for specific site investigation activities. The sampling event was conducted in accordance with the EPA-approved *Site Sampling Plan – Revision 6*, dated June 9, 2005.

3.1 SITE CONDITIONS

The site currently exists in an industrialized area as a small, sandy strip of land. No buildings or other structures currently exist on site. Two railroad tracks traverse through the former site; a fenced field that previously housed bulk fuel tanks exists to the north, Evergreen Avenue is to the east, Buffalo Avenue lies to the west, and the Support Terminals facility lies to the south. Vegetation is limited over most of the site due to the sandy soil type. No runoff routes were identified during sampling activities, and all rainfall likely percolates directly into the sandy soil. Residential areas exist to the north and south, approximately 0.25 mile from the site.

3.2 SAMPLE COLLECTION METHODOLOGY AND PROCEDURES

TN&A personnel collected 20 surface soil samples and 5 subsurface samples during the week of June 13, 2005. Sampling locations are illustrated in Figure 3, and are summarized in Tables 1 and 2. Table 3 illustrates sample analytical methodology, containers, and preservatives. All sample collection activities and procedures were performed in accordance with the November 2001 USEPA Region 4, *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual* (EISOPQAM). Additional quality assurance/quality control (QA/QC) samples such as trip, rinsate and preservative blanks, duplicate samples (two surface soil, one subsurface soil) and matrix spike/matrix spike duplicate samples were collected as required by the EISOPQAM. All glassware was "Quality Certified" and included a certificate of compliance.

Soil samples collected from the Support Terminals property were split with Mr. Dylan Morgan, P.G., from Kanab Terminals (owner of Support Terminals). The samples were collected by TN&A and relinquished to Kanab under proper chain-of-custody procedures. The laboratory analyses for these samples were performed by a third-party selected by Kanab and were not released to TN&A.

Surface soil samples were collected using stainless-steel spoons and bowls. Surface soil samples were collected from ground surface to approximately 4 inches below ground surface (bgs). Soil was placed into the bowls from the ground and homogenized. Portions of soil for the volatile organic compound (VOC) analysis were collected from the ground and placed directly into the sample jars with zero headspace. Subsurface soil samples were collected from between 2–3 feet in depth using stainless-steel soil augers. One auger bucket was used to advance to depth, and a second auger bucket was used for the collection of the sample. Soil used for VOC analysis was collected directly from the auger bucket. The remaining soil was homogenized in a stainless-steel bowl then placed into sample containers.

3.3 BACKGROUND SAMPLES

The background surface and subsurface soil samples (BUF-01-SS/BUF-01-SB) were collected west of Buffalo Avenue, approximately 250 feet west of the site in a location believed to be characteristic of undisturbed soil in the area unaffected by site activities. Sample results are discussed in Section 4.0 and 5.0.

3.4 ANALYTICAL SUPPORT AND METHODOLOGY

All samples collected during the PA/SI were processed and tracked using EPA *FORMS II Lite* sample tracking software. EPA selected the analytical service providers (laboratories) through the Contract Laboratory Program (CLP). CLP laboratories analyzed all soil samples for EPA Target Compound List (TCL) VOCs, extractable semi-volatile organic compounds (SVOCs), pesticides and polychlorinated biphenyls (PCBs), and Target Analyte List (TAL) metals and cyanide.

The laboratories submitted all analytical data to EPA Region 4 Science and Ecosystems Support Division (SESD) for analytical validation and compliance with CLP terms. Validated data results for this report were then issued to TN&A. Analytical data sheets are provided on CD ROM in Appendix E.

3.5 ANALYTICAL DATA QUALITY AND DATA QUALIFIERS

All analytical data are subject to a QA review, as described in the EPA SESD laboratory data evaluation guidelines. In the text and analytical data tables in this PA/SI report, some concentrations of organic and inorganic parameters are qualified with a "J." A "J" qualifier indicates that the qualitative analysis is acceptable; although the quantitative value is only estimated. Other compounds are qualified with an "N," indicating detection on presumptive evidence of their presence. This means that compound identification is only tentative; presumptive detection cannot be considered a positive indication of its presence. Results of some sample analyses are qualified with a "U," meaning that the constituent was analyzed for, but not detected. The reported number is the laboratory-derived minimum quantitation limit (MQL) for the constituent in that sample. Sample results qualified with an "R" indicate the data were rejected and unusable.

4.0 SOURCE SAMPLING

This section discusses the source evaluated at the site, and details the sampling locations and analytical results from samples collected therein. Based on sampling results, the source of contamination is considered to be approximately 0.25 acre of lead and PCB-1254 contaminated soil resulting from possible lead smelter activities at the former FSC Buffalo site. These activities have ceased and all site structures have been removed.

4.1 SOURCE SAMPLE LOCATIONS

Nineteen surface soil samples were collected from the approximate location of the former FSC Buffalo operation, as well as surrounding locations in order to delineate potential migration. One background sample was collected from approximately 250 feet west of the site. Four subsurface samples were collected from the four corners of the approximate location of the FSC Buffalo building. A subsurface sample was also collected from the background location. Soil sampling locations are illustrated in Figure 3 and described in Tables 1 and 2. Photographs of sampling locations are provided in Appendix C.

4.2 SOURCE ANALYTICAL RESULTS

Analytical result summaries for soil samples are provided in Tables 4 and 5 located at the end of the text. HRS-elevated concentrations are shaded. HRS-elevated concentrations are defined as concentrations identified at or above three times the background concentration, or concentrations in excess of the detection limit of a non-detect background result. For secondary comparison purposes, EPA Region 9 Preliminary Remediation Goals (PRGs) for industrial soil are included in the column on the right (Ref. 12). PRG values are generic risk-based concentrations for evaluating contaminated sites. Sample concentrations exceeding any one of these guidance values are shown in bold. Analytical data sheets listing all results are located in Appendix E.

Analytical results revealed several contaminants at HRS-elevated concentrations in both surface and subsurface soil at FSC Buffalo. The contaminants of greatest concern that were considered site-attributable were lead and PCB-1254. The highest detection of lead [14,000 milligrams per kilogram (mg/kg)] was identified in surface soil sample BUF-04-SS, located in the southwest corner of the former FSC Buffalo operation building. Lead (840 mg/kg) was also detected in the subsurface sample at this location (-04-SB). These detections were elevated in comparison with background concentrations and were also above EPA Region 9 PRGs for lead (800 mg/kg). Lead was detected at elevated concentrations at several other locations including surface and subsurface samples -05-SS and -05-SB, located in the southeast corner of the former FSC structure. Unexpectedly, lead was detected in sample -19-SS at 2,000 mg/kg, collected from inside the gated, grassy area owned by Support Terminals. Samples between the former FSC structure and Support Terminals including -12-SS, -13-SS, and -20-SS were not elevated. Based on the sampling results and pattern of these samples, it is not likely that lead has migrated to the -19-SS location as a result of FSC Buffalo operations, and contamination in that sample was not considered site attributable.

Lead was also detected at 1,100 mg/kg in surface soil sample -14-SS located several hundred feet to the west across Buffalo Avenue. This detection is not considered site-attributable since sample -10-SS, located 100 feet west of the former structure (in between -14-SS and -04-SS), was not identified at HRS-elevated levels.

Arsenic was detected in several samples at elevated concentrations in surface and subsurface soils and was detected in the background surface soil sample, -01-SS, at 3.9 mg/kg. Arsenic is not a common contaminant resulting from lead smelting activities and the metal is not considered site-attributable. Several SVOCs were also detected in surface and subsurface soils. SVOCs [mostly polycyclic aromatic hydrocarbons (PAHs)] were detected at elevated concentrations in samples -02-SS, -06-SS, -14-SS, and -05-SB. Locations abovementioned are in close proximity to railroad tracks and/or Buffalo Avenue. SVOCs (including PAHs) are prevalent in areas surrounded by asphalt and in areas with regular vehicular traffic.

PCB-1254 was detected in surface samples -04-SS and -05-SS, as well as subsurface sample -04-SB. Samples -04-SS and -04-SB were collected at the southwest corner of the former FSC structure with elevated concentrations of PCB-1254 at 450 micrograms per kilogram (μg/kg) and 460 μg/kg, respectively. Sample -05-SS was collected from the southeast corner of the former FSC structure at the elevated concentration of 110 μg /kg. PCB-1254 is considered to be site attributable since historic industrial activities may have used PCB oils in either electrical transformers or other equipment. PCB-1254 was not detected above EPA Region 9 PRGs in any sample.

4.3 SOURCE CONCLUSIONS

Despite several HRS-elevated contaminants identified on site, only lead (14,000 mg/kg) and PCB-1254 (460 μg/kg) are considered site-attributable (resulting from the lead smelter activities). All other HRS-elevated compounds were not considered site-attributable, since most were detected near roadways and/or railroad tracks and are unlikely to have been a result of lead smelting activities.

5.0 PATHWAYS

This section discusses the groundwater migration, surface water migration, soil exposure, and air migration pathways associated with an HRS evaluation, the targets associated with each pathway, and pathway-specific conclusions. Sampling locations and analytical results for samples collected from the specific pathways are also discussed.

5.1 GROUNDWATER MIGRATION PATHWAY

The groundwater migration pathway is a potential concern because all potable water in the study area is from groundwater sources. All community water systems draw water from the Floridan aquifer. The deeper, confined, artesian characteristics of the Floridan aquifer reduce the likelihood of site contamination migrating into the aquifer. Private wells may also exist in the study area; however, none have been identified. Regional geology and municipal/community well systems are discussed below.

The Jacksonville area is located in the Coastal Lowlands region of the Coastal Plain physiographic province of Florida. The Coastal Lowlands region ranges in elevation from sea level to about 100 feet above msl (Ref. 13, pp. D-6, D-7, D-8). The Coastal Plain consists of consolidated and unconsolidated geologic units that slope and thicken seaward from the fall line (Ref. 14, pp. B-10, B-11). The terrain in the Costal Lowlands region is characterized by barrier islands, marshes, and level plains, as well as a series of five terraces formed during the most recent transgressions and regressions of the ocean.

Geologic units that underlie the area, in descending stratigraphic order, include the following: post-Miocene deposits; the Hawthorn Group (consisting of the Coosawhatchee, Marks Head, and Penney Farms Formations); the Ocala Group; and the Avon Park, Oldsmar, and Cedar Keys Formations (Refs. 14, p. B-58; 15, p. 19). Post-Miocene deposits consist of a basal sequence overlain by alluvial and terrace deposits. About 100 feet thick, these deposits consist of sand, gravel, clay, shells, limestone, and marl (Ref. 14, p. B-38). The Coosawhatchee Formation of the Hawthorn Group consists of quartz sands, dolostone, and clays (Ref. 15, p. 41). The Marks Head Formation of the Hawthorn Group consists of interbedded sands, clays, and dolostone. The Penney Farms Formation of the Hawthorn Group consists of carbonated units, with interbedded sand and clays (Ref. 15, p. 34). The thickness of the Hawthorn Group in the Jacksonville Basin is greater than 500 feet (Ref. 15, p. 15).

The Ocala Group can be divided into two parts based on lithology: the upper part consists of coarse-grained limestone, and the lower part consists of fine-grained soft limestone (Ref. 14, p. B-30). The total thickness of the Ocala Limestone in the Jacksonville area is approximately 400 feet (Ref. 14, Plates 2 and 9). The Avon Park Formation consists of locally micritic, pelletal limestone and is approximately 800 feet thick (Ref. 14, B-26). The Oldsmar Formation consists of micritic to finely pelletal limestone, interbedded with fine to medium crystalline, commonly vuggy dolomite, and is approximately 400 feet thick (Ref. 14, p. B-22). The Cedar Keys Formation can also be divided into two parts based on lithology. The upper part of the Cedar Keys Formation consists of coarsely crystalline dolomite that is moderately to highly porous. The lower portion of the Cedar Keys consists of finely crystalline to microcrystalline dolomite interbedded with anhydrite. The thick anhydrite beds form the lower confining unit of the Floridan aquifer (Ref. 14, pp. B-18, B-19). The Cedar Keys Formation is approximately 500 feet thick in the Jacksonville area (Ref. 14, p. B-58).

The two major sources of groundwater in the Jacksonville area are the surficial aquifer and the underlying Floridan aquifer system (Ref. 14, p. B-40). The surficial aquifer is separated from the Floridan aquifer system by the confining beds of the Hawthorn Formation. The surficial aquifer is in the permeable units of the post-Miocene deposits, and groundwater in the surficial aquifer is generally under unconfined conditions (Ref. 13, p. D-18). The water level in the surficial aquifer fluctuates seasonally, corresponding to variations in precipitation. The elevation of the water table is estimated to be at or slightly above sea level in the Jacksonville area. The surficial aquifer is recharged primarily by precipitation and is generally hydrologically interconnected with water from lakes, streams, and marshes (Ref. 13, p. D-18). In the Jacksonville area, the elevation of the potentiometric surface of the Floridan aquifer system is higher than the elevation of the water table. As a result, the surficial aquifer may also be recharged by upward leakage from the Floridan aquifer system (Ref. 13, p. D-18).

The northern Floridan aquifer system consists of permeable units of the Suwannee Limestone, Ocala Group and the Avon Park Formation, the Oldsmar Formation, and the Cedar Keys Formations (Ref. 16, p. 20). In the Jacksonville area, the top of the Floridan aquifer system ranges from approximately 400–550 feet bgs, and the thickness ranges from 1,800–2,200 feet (Ref. 16, pp. 68, 73). In northeast Florida, the Floridan aquifer system is divided into the Upper and Lower Floridan aquifers (Ref. 13, p. D-17). Low permeability beds located in the basal part of the Ocala Group and the upper part of the Avon Park Formation comprise the middle semi-confining unit that separates the two aquifers (Ref. 13, p. D-22). Groundwater in the Floridan aquifer system occurs in joints, faults, bedding planes, and other secondary porosity openings. These openings can become enlarged in carbonate rocks through solution

by circulating groundwater (Ref. 13, p. D-25). Therefore, karstic groundwater flow can occur in the Floridan aquifer. However, because of the thickness of the Hawthorn Group in the Jacksonville area, sinkholes have not developed in the Jacksonville area (Refs. 4; 16, p. 33).

The Fernandina permeable zone, a high-permeability unit of subregional extent, occurs at the base of the Lower Floridan aquifer in the Jacksonville area (Ref. 14, p. B-70). The Fernandina permeable zone in the Jacksonville area occurs within the permeable units in the Cedar Keys Formation at a depth of about 2,200 feet (Ref. 14, pp. B-26, B-38). This zone is confined above by low-permeability beds in the lowermost Avon Park Formation and below by low-permeability beds in the Cedar Keys Formation (Ref. 14, p. B-58). Groundwater in the uppermost part of the Fernandina permeable zone is fresh; however, groundwater with high salinity occurs throughout the rest of the zone (Ref. 14, p. B-58). Upward migration of saline water from the Fernandina permeable zone into the shallower permeable zones in the Floridan aquifer system has occurred in the Jacksonville area in response to heavy pumping of the Upper Floridan aquifer. Near vertical faults in the area act as conduits that allow the migration of groundwater from the Fernandina permeable zone to the Upper Floridan aquifer (Ref. 14, B-71).

Water recharges the Floridan aquifer system three ways: (1) through breaches in the confining layers caused by sinkholes; (2) by downward leakage where the confining layers are thin or absent; and (3) by direct entry where the aquifer system is exposed at the surface. The principal recharge areas of the Floridan aquifer system near Jacksonville occur to the south and west in portions of western Putnam and Clay Counties and eastern Alachua and Bradford Counties (Ref. 16, pp. 84, 85). These recharge areas occur well outside of the 4-mile study area.

The Jacksonville Electric Authority (JEA) provides the majority of municipal water in Jacksonville via a system of 33 water treatment plants utilizing approximately 100 artesian wells developed into the Floridan aquifer (Refs. 17, 18). The 33 plants are divided into the North Grid and South Grid, with 10 plants providing water to an estimated population of 420,989 in the North Grid, and 23 plants providing water to an estimated 396,461 people in the South Grid (Ref. 19). Several additional independent water plants have also been acquired by JEA. Prior to 2002, United Water of Florida (UWF) operated several smaller municipal/community water treatment plants in Jacksonville. In December 2001, UWF sold its regulated properties to JEA and formed a "public-private partnership" (Ref. 18).

Thirty-five municipal/community wells from nine different water treatment plants were determined to be within a 4-mile radius of site (Refs. 4, 19). Table 6 lists the water systems and apportioned target

populations identified in the Floridan aquifer (Refs. 4, 19–22). The following JEA water plants were identified within 4 miles of site: North Grid – Main St (9 wells), McDuff (8 wells), and Norwood (4 wells); South Grid – Arlington (4 wells total, 3 wells within 4-mile radius) and Lake Lucina (3 wells) (Refs. 17–20). The North Grid includes 47 wells from 10 water plants and serve a total of 420,989 people, averaging 8,957 people per well. The South Grid includes 45 wells from 23 plants and serves a total of 396,461 people, averaging 8,810 people per well (Refs. 19, 20).

Additional independent JEA or historical UWF water plants were also identified within 4 miles of site including Woodmere, Lake Forrest, Magnolia Gardens, and the Jacksonville University. The Woodmere system contains 3 wells and serve a total of 4,565 people, averaging 1,522 people per well. Lake Forrest and Magnolia Gardens have one well each serving 840 connections and 701 connections respectively (Refs. 19, 21). When multiplied by the average number of persons per household (2.51), Lake Forrest serves is 2,108 people and Magnolia Gardens serves 1,760 people (Refs. 19, 22). The Jacksonville University system contains 3 wells that serve 848 people, averaging 283 people per well (Refs. 19, 20).

5.2 SURFACE WATER MIGRATION PATHWAY

The surface water migration pathway is of minimal concern at FSC Buffalo and was not evaluated. Surface water samples were not collected during the sampling investigation. FSC Buffalo has no significant surface water drainage features. Based on the topography, storm water does not appear to runoff from the site. The tidal St. Johns River is located 0.35 mile east of the site (Ref. 4). There are several industrial properties located between site and the St Johns River. The St. Johns River travels north then east about 12 miles and then discharges into the Atlantic Ocean (Ref. 4). The 15-mile Target Distance Limit terminates within the St. Johns River at the Atlantic Ocean. The St. Johns River is a large fishery and recreational surface water body (Ref. 23). The river provides designated critical habitat for the federally endangered Florida manatee, and several miles of wetland areas exist in the more distant portions of the 15-mile TDL, near the Atlantic Ocean (Refs. 24, 25).

The large size, tidal characteristics, and moderate flow rate (3,696 cubic feet per second) of the river prohibit the generation of significant potential contamination target values within the surface water pathway (Refs. 23, 26). The river characteristics and industrial development along its shores also create attribution issues that complicate using the St Johns River in scoring the surface water pathway for the site (Refs. 4, 23, 26).

5.3 SOIL EXPOSURE PATHWAY

The soil exposure pathway is of potential concern at FSC Buffalo since CSX workers may be present in this industrialized area and residences are within 0.25 mile from the site. Although no information has been identified about the on-site operations, smelting activities can emit significant amounts of metal fume that may be carried by wind currents (Ref. 10). Although sampling data determined several HRS-elevated analytes in surface and subsurface soils, only lead and PCB-1254 are considered to be site-attributable.

5.3.1 Physical Conditions

FSC Buffalo is located in an industrial area, with no buildings or other structures currently on site. Two railroad tracks traverse through the former site; a fenced field exists to the north, Evergreen Avenue is to the east, Buffalo Avenue lies to the west, and the Support Terminals facility lies to the south. Vegetation is limited over most of the site due to the sandy soil type. No runoff routes were identified during sampling activities. Residential areas exist to the north and south, approximately 0.25 mile from the site.

5.3.2 Soil Exposure Sample Locations and Analytical Results

All surface soil samples were collected within the top 4 inches and are considered accessible for direct contact. Subsurface soil samples were collected from between 2–3 feet in depth. Soil sample locations are illustrated in Figure 3 and analytical results are presented in Tables 4 and 5. On-site surface and subsurface soil sampling locations and analytical results were discussed in detail in Section 4.0. The on-site HRS-elevated concentrations included detections of several analytes; however, only lead (14,000 mg/kg) and PCB-1254 (460 μg/kg) were considered to be site attributable. The lead concentration in sample -04-SS exceeded its respective guidance value.

5.3.3 Soil Targets

Residents are located approximately 0.25 mile from the former FSC site. Nearby populations include 163 people within 0.25 mile of site, 1,491 people between 0.25 – 0.5 mile, and 4,059 people between 0.5 – 1 mile from site (Refs. 22, 27). An estimated 20 workers are considered to be on site since CSX uses the traversing rail lines. There are no known terrestrial sensitive environments on site.

5.3.4 Soil Conclusions

Several metals and organic constituents were present at HRS-elevated concentrations in surface and subsurface soil samples at FSC Buffalo; however, only three samples (-04-SS, -04-SB, and -05-SS)

contained site-attributable contaminants at elevated levels. Lead was identified in -04-SS at 14,000 mg/kg, and in -04-SB at 840 mg/kg. Both lead concentrations were above the EPA Region 9 PRG of 800 mg/kg. Lead was detected in sample -05-SS at 360 mg/kg. PCB-1254 was detected at 450 μg/kg in -04-SS, and 100 μg/kg in -05-SS. PCB-1254 was also detected at 460 μg/kg in -04-SB. PCB-1254 was not detected above the guidance value of 740 μg/kg in any sample.

Although lead smelting activities may have occurred at the site, the identification of only one lead concentration exceeding its guidance value fails to indicate a large-scale smelting operation occurred here that may represent a threat to nearby residents. This singularly high result likely suggests that a more specific local source (dumped battery) may have been the source of the one high lead detection rather than an industrial smelting operation.

5.4 AIR MIGRATION PATHWAY

The air migration pathway is of minimal concern at FSC Buffalo as no air samples have ever been collected during smelting operations and these operations no longer occur on site. Although the air pathway may have been a threat during smelting operations over 40 years ago, the air pathway was not sampled or evaluated.

6.0 SUMMARY AND CONCLUSIONS

FSC Buffalo was identified in a study of former lead smelting facilities that was published in the *American Journal of Public Health* and reported by ABC News (Refs. 1, 2). The study identified approximately 430 former lead smelting sites that may contain potentially hazardous soil lead levels and are "unrecognized in the United States" (Ref. 3). The site currently exists in an industrialized area as a small, sandy area of land. No buildings or other structures currently exist on site. Two railroad tracks traverse through the former site; a fenced field exists to the north, Evergreen Avenue is to the east, Buffalo Avenue lies to the west, and the Support Terminals facility lies to the south.

Nineteen surface soil samples were collected from the approximate location of the former FSC Buffalo operation, as well as surrounding locations in order to delineate potential migration. One background sample was collected from approximately 250 feet west of the site. Four subsurface samples were

collected from the four corners of the approximate location of the FSC Buffalo building. A subsurface sample was also collected from the background location.

Despite several HRS-elevated contaminants identified on site, only lead (14,000 mg/kg) and PCB-1254 (460 µg/kg) were considered site-attributable (resulting from the lead smelter activities). All other HRS-elevated compounds were not considered a site-attributable as most were detected near roadways and/or railroad tracks.

After an HRS evaluation based on recent analytical results, the site failed to generate an appreciable HRS site score. The score was driven by the soil exposure pathway and the groundwater migration pathway. No further investigations are recommended; however, subsequent federal actions are to be determined by EPA.

REFERENCES

1. Eckel, W. P., Rabinowitz, M.B., and Foster, G.D. *Discovering Unrecognized Lead-Smelting Sites by Historical Methods.* American Journal of Public Health, Volume 91, Issue 4 625-627. April 2001.

2. ABC News. *Lead-Filled Lots.* Story by Rose Palazzolo. April 3, 2001.

3. U.S. Environmental Protection Agency (EPA). Site Determination to enter a site into CERCLIS. Prepared by Wesley S. Hardigree, EPA, and Teresa Kinner, Florida Department of Environmental Protection. October 25, 2002.

4. U.S. Geological Survey (USGS). 7.5-minute Series Topographic Quadrangle Maps of Florida: Jacksonville 1994, Eastport 1992, Dinsmore 1992, Trout River 1994, and Marietta 1992.

5. Duval County. Historic plat map survey. Panel 365 of Sheet 250, Volume 2. June 1949.

6. City of Jacksonville. JaxGIS – Geographical Information System database. Property information near the FSC Buffalo Avenue site. Internet address: http://www.coj.net/Departments/Property+Appraiser/Default.htm. Accessed April 4, July 21, and November 13, 2003.

7. Southeast Regional Climate Center. Temperature Summary for Jacksonville WSO, Florida from 1948 to 2003. Internet Address: http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?fl4358. Accessed October 30, 2003.

8. U.S. Department of Commerce (USDC). "Climatic Atlas of the United States." National Oceanic and Atmospheric Administration. Washington, DC. 1983.

9. USDC. "Rainfall Frequency Atlas of the United States." Washington, DC. 1961.

10. Occupational Safety and Health Administration. Secondary Lead Smelter eTool: Smelting. Internet address: http://www.osha.gov/SLTC/etools/leadsmelter/index.html. Accessed November 3, 2003.

11. TN&A. Field Logbook. Notes from site reconnaissance performed April 11, 2003.

12. EPA Region 9. Preliminary Remediation Goals (PRG). Guidance values for industrial soil. October 2004.

13. Krause, Richard E. and Randolph, Robert B. "Hydrology of the Floridan Aquifer System in Southeast Georgia and Adjacent Parts of Florida and South Carolina." USGS Professional Paper 1403-D. Washington, DC. 1989.

14. Miller, James A. "Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina." Professional Paper 1403-B. Washington DC. 1986.

15. Scott, Thomas M. "The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida." Florida Geological Survey, Bulletin No. 59. Tallahassee, Florida. 1988.

16. Florida Geological Survey. "Florida's Groundwater Quality Monitoring Program – Hydrogeological Framework." Special Publication No. 32. Tallahassee, Florida. June 1991.

REFERENCES (Continued)

17. Jacksonville Electric Authority (JEA). *2002 Annual Water Quality Report*. Internet address: http://www.jea.com/about/pub/downloads/quality/2002WaterQualityReport.pdf. Accessed March 2004.

18. United Water of Florida (UWF). Press Release, December 28, 2001. "JEA and United Water Complete $219 Million Transaction." Internet address: http://www.unitedwater.com/pr122701.htm. Accessed November 11, 2003.

19. TN&A. Project Note regarding municipal well locations and population apportionment for municipal/community wells. Well locations provided by FDEP, JEA, and UWF and apportionment calculations determined by G. Kowalski, Project Scientist, TN&A. March 2004.

20. FDEP. "Drinking Water, Basic Facility Reports." Microsoft Excel file extracted from District 2 database filtered for Community and Non-Community (day care) water systems in Jacksonville, February 20, 2003. Internet address: http://www.dep.state.fl.us/water/drinkingwater/download.htm. Accessed April 23, 2003.

21. UWF. Summary table of UWF facilities in Jacksonville. July 2001.

22. U.S. Census Bureau. Year 2000 population statistics for Duval County, Florida. Internet address: http://quickfacts.census.gov/qfd/states/12/12031.html. Accessed April 22, 2003.

23. St. Johns River Alliance. St. Johns River – An American Heritage River. Recreational activities and topographic facts of the St. Johns River. Internet address: http://www.floridariver.org. Accessed November 12, 2003.

24. U.S. Fish and Wildlife Service, Division of Endangered Species. Species Accounts – West Indian Manatee. August 1993.

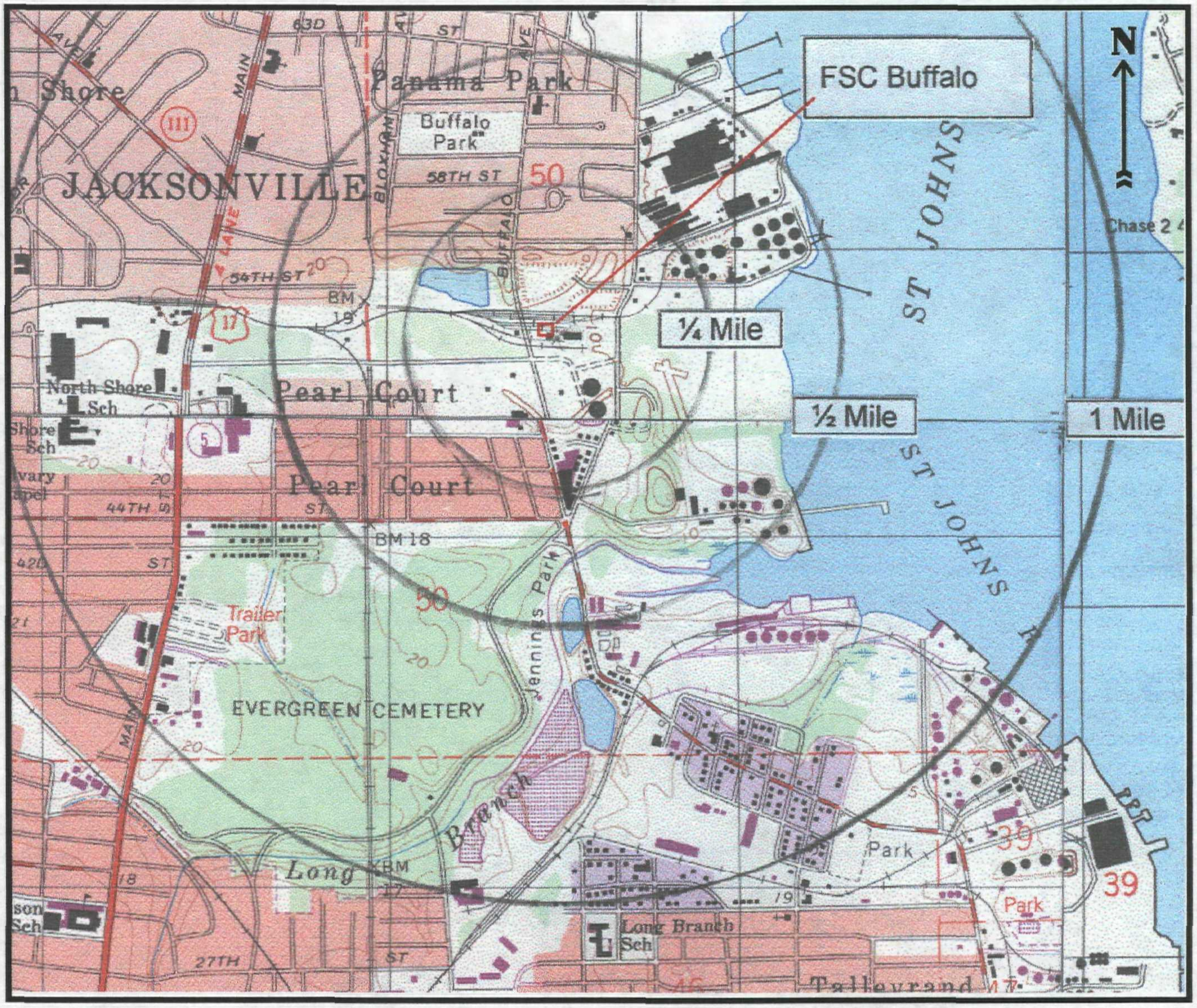
25. St. Johns River Water Management District. Water Resources Atlas – Duval County. FEMA 100-Year Floodplain and National Wetlands Inventory Map. Internet address: http://sjr.state.fl.us/programs/outreach/local_gov/map_atlas/duval/duval_floodplain.pdf. Accessed November 12, 2003.

26. USGS. Surface Water Data for Florida: Calendar Year Streamflow Statistics – St. Johns River at Jacksonville Florida. Internet address: http://nwis.waterdata.usgs.gov/fl/nwis/annual … Accessed November 12, 2003.

27. USCB. Landview® V DVD. Population estimator using 2000 Census information.

Appendix A

Figures



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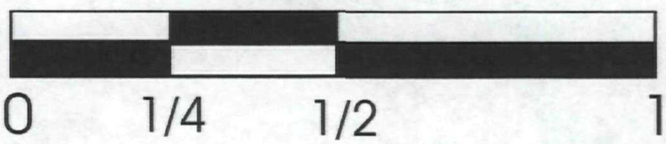
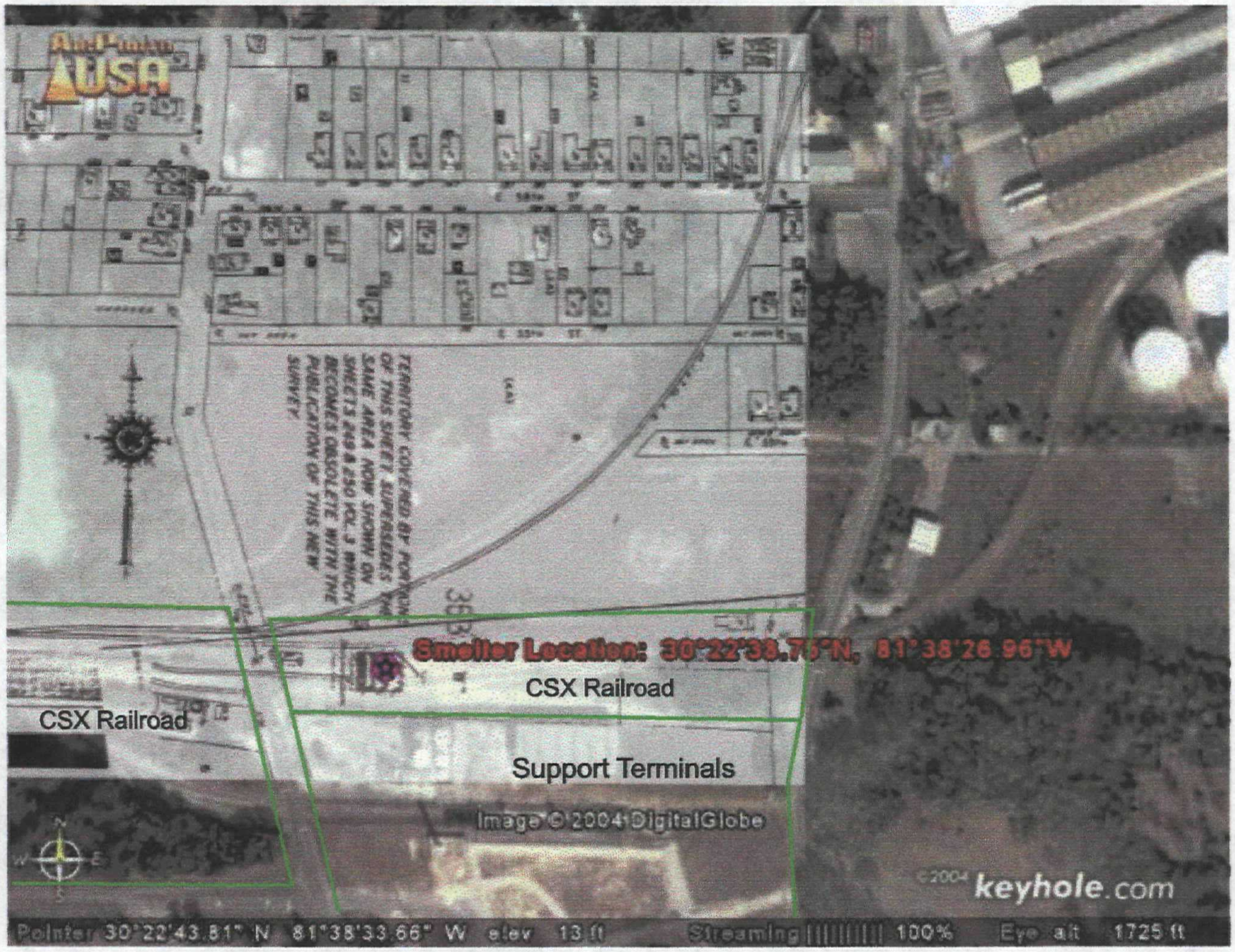


FLORIDA SMELTING COMPANY
BUFFALO AVENUE
EPA ID No. FLD000407555
Jacksonville, Duval County, Florida

FIGURE 1 - TOPOGRAPHIC MAP

T N & Associates, Inc.
Engineering and Science



Aerial Photograph Source: DigitalGlobe 2004
Overlay Plat Map Source: Sanborn Map 1949
Property information obtained from Duval County Property Appraiser.

LEGEND

PROPERTY LINES

FLORIDA SMELTING COMPANY
BUFFALO AVENUE
EPA ID No. FLD000407555
Jacksonville, Duval County, Florida

FIGURE 2 - Aerial Photograph with Sanborn Overlay

T N & Associates, Inc.
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LEGEND

Plat Map/Photograph Source:
Duval County Property Appraiser, November 2003.

- SURFACE SOIL SAMPLE ONLY
- SURFACE AND SUBSURFACE SOIL SAMPLE
- APPROXIMATE FORMER BUILDING LOCATION
- 5 SAMPLE NUMBER (05-SS and 05-SB)
- RAILROAD TRACKS
- PROPERTY LINES

FLORIDA SMELTING COMPANY
BUFFALO AVENUE
EPA ID No. FLD000407555
Jacksonville, Duval County, Florida

FIGURE 3- Soil Sampling Locations

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Engineering and Science

Appendix B

Tables

TABLE 1
SURFACE SOIL SAMPLING LOCATIONS

Sample Number	Location	Rationale
BUF-01-SS	Background; 250 feet west of site, west of Buffalo Avenue	Background sample for comparison to other samples
BUF-02-SS	Northwest corner of former structure	Determine presence or absence of hazardous constituents
BUF-03-SS	Northeast corner of former structure	Determine presence or absence of hazardous constituents
BUF-04-SS	Southwest corner of former structure	Determine presence or absence of hazardous constituents
BUF-05-SS	Southeast corner of former structure	Determine presence or absence of hazardous constituents
BUF-06-SS	100 feet northwest of former structure	Determine presence or absence of hazardous constituents
BUF-07-SS	100 feet northeast of former structure	Determine presence or absence of hazardous constituents
BUF-08-SS	200 feet east-northeast of former structure	Determine presence or absence of hazardous constituents
BUF-09-SS	300 feet east-northeast of former structure	Determine presence or absence of hazardous constituents
BUF-10-SS	100 feet southwest of former structure	Determine presence or absence of hazardous constituents
BUF-11-SS	100 feet southeast of former structure	Determine presence or absence of hazardous constituents
BUF-12-SS	200 feet east-southeast of former structure	Determine presence or absence of hazardous constituents
BUF-13-SS	300 feet east-southeast of former structure	Determine presence or absence of hazardous constituents
BUF-14-SS	150 feet west-southwest of former structure	Determine presence or absence of hazardous constituents
BUF-15-SS	200 feet southwest of former structure	Determine presence or absence of hazardous constituents
BUF-16-SS	150 feet south-southwest of former structure (ST property)	Determine presence or absence of hazardous constituents
BUF-17-SS	200 feet south of former Structure (ST property)	Determine presence or absence of hazardous constituents
BUF-18-SS	300 feet south-southeast of former structure (ST property)	Determine presence or absence of hazardous constituents
BUF-19-SS	400 feet southeast of former structure (ST property)	Determine presence or absence of hazardous constituents
BUF-20-SS	350 feet southeast of former structure (ST property)	Determine presence or absence of hazardous constituents

Notes: BUF Florida Smelting Company – Buffalo Avenue
SS Surface soil sample
ST Support Terminals

TABLE 2

SUBSURFACE SOIL SAMPLING LOCATIONS

Sample Number	Location	Rationale
BUF-01-SB	Background; 250 feet west of site, west of Buffalo Avenue	Background sample for comparison to other samples
BUF-02-SB	Northwest corner of former structure	Determine presence or absence of hazardous constituents
BUF-03-SB	Northeast corner of former structure	Determine presence or absence of hazardous constituents
BUF-04-SB	Southwest corner of former structure	Determine presence or absence of hazardous constituents
BUF-05-SB	Southeast corner of former structure	Determine presence or absence of hazardous constituents

Notes: BUF Florida Smelting Company – Buffalo Avenue
SB Subsurface soil sample

TABLE 3

ANALYTICAL METHODOLOGY, SAMPLE CONTAINERS, AND PRESERVATIVES

Matrix	Analysis	EPA Method	Sample Container	Preservative
Soil	VOA	CLP	Two 2-oz. glass jars with septum lid	Cool to 4 °C
	BNA/Extractable Pesticides/PCBs	CLP	One 8-oz. glass jar	Cool to 4 °C
	Metal CN	CLP	One 8-oz. glass jar	Cool to 4 °C
Ground-water	VOA	CLP	Three 40-ml glass jars with septum lid	HCl to pH < 2, Cool to 4 °C
	BNA/Extractable	CLP	Two 1-liter amber glass	Cool to 4 °C
	Pesticides/PCBs	CLP	Two 1-liter amber glass	Cool to 4 °C
	Metal	CLP	One 1-liter poly jar	HNO_3 to pH < 2, Cool to 4 °C
	CN	CLP	One 1-liter poly jar	NaOH to pH > 12, Cool to 4 °C
Sediment	VOA	CLP	Two 2-oz. glass jars with septum lid	Cool to 4 °C
	BNA/Extractable Pesticides/PCBs	CLP	One 8-oz. glass jar	Cool to 4 °C
	Metal CN	CLP	One 8-oz. glass jar	Cool to 4 °C

Notes:

VOA	Volatile organic analysis	oz	Ounce
BNA	Base, neutral, and acid extractables	°C	Degree Celsius
PCB	Polychlorinated biphenyl	CN	Cyanide
CLP	Contract Laboratory Program	<	Less than
>	Greater than	HCl	Hydrochloric acid
NaOH	Sodium hydroxide	HNO_3	Nitric acid

TABLE 4
SURFACE SOIL SAMPLE RESULTS

Analyte	Back-Ground	On Site										Guidance
		Florida Smelting Company, Buffalo Avenue										PRG[b]
	BUF-01-SS	BUF-02-SS	BUF-03-SS	BUF-04-SS	BUF-05-SS	BUF-06-SS	BUF-07-SS	BUF-08-SS	BUF-21-SS[a]	BUF-09-SS	BUF-10-SS	
Metals (mg/kg)												
Arsenic	**3.9 J**	**30 J**	1.5 J	**8.1 J**	**5.3 J**	**34 J**	**67 J**	**5.8 J**	**5.7 J**	**28 J**	**9.4 J**	1.6
Barium	84 J	43 J	9.3 J	11 J	--	60 J	22 J	34 J	33 J	21 J	13 J	67,000
Beryllium	0.07 UJ	--	--	--	--	--	--	--	--	--	--	1,900
Cadmium	0.63 J	0.46 J	0.04 R	0.21 J	0.23 J	0.77 J	0.35 J	5.5 J	3.0 J	0.42 J	0.10 J	450
Cobalt	1.2 J	1.6 J	0.25 J	0.27 J	0.30 J	2.6 J	1.7 J	1.1 J	0.94 J	0.94 J	0.49 J	1,900
Chromium	12 J	7.7 J	2.5 J	5.9 J	4.2 J	13 J	6.4 J	25 J	18 J	7.1 J	4.7 J	450
Copper	28 J	18 J	1.8 J	33 J	7.3 J	37 J	21 J	9.5 J	8.6 J	14 J	8.6 J	41,000
Nickel	5.8 J	5.5 J	--	--	1.7 J	9.9 J	5.9 J	5.1 J	4.5 J	4.5 J	2.3 J	20,000
Lead	92 J	260 J	65 J	**14000 J**	360 J	330 J	200 J	280 J	260 J	85 J	220 J	800
Antimony	6.9 UJ	1.0 R	--	74 J	4.0 J	2.0 J	3.0 J	1.6 R	1.7 J	6.5 UJ	2.0 J	410
Thallium	2.9 U	--	--	--	--	--	--	--	--	--	--	67
Vanadium	8.3 J	11 J	3.8 J	10 J	4.7 J	13 J	11 J	14 J	13 J	9.8 J	5.0 J	1,000
Zinc	180 J	140 J	22 J	74 J	48 J	140 J	52 J	90 J	72 J	60 J	39 J	100,000
Total Mercury	0.06 UJ	--	--	--	--	--	--	--	--	--	--	310
Aluminum	2200 J	2600 J	1300 J	3800 J	2700 J	3300 J	1800 J	1600 J	1700 J	2700 J	2600 J	100,000
Manganese	81 J	90 J	13 J	9.5 J	12 J	160 J	79 J	49 J	41 J	56 J	22 J	19,000
Magnesium	860 J	390 J	75 J	150 J	280 J	630 J	160 J	120 J	130 J	690 J	490 J	—
Iron	10000	8300	1100	3700	1500	18000	9800	4800	3400	4400	2200	100,000
Volatiles (µg/kg)												
Acetone	12 UJ	23	--	--	--	--	--	--	--	--	--	54,000,000
Methyl Ethyl Ketone	12 UJ	--	--	--	--	--	--	--	--	--	--	110,000,000
Semi-volatiles (µg/kg)												
Acetophenone	380 U	--	--	--	--	43 J	--	--	--	--	--	—
1,1-Biphenyl	380 U	--	--	--	--	--	--	--	--	--	--	23,000,000
2-Methylnaphthalene	380 U	160 J	--	--	44 J	160 J	62 J	43 J	45 J	86 J	--	—
Naphthalene	380 U	160 J	--	--	--	140 J	52 J	47 J	46 J	90 J	--	190,000
Acenaphthylene	120 J	310 J	59 J	--	--	990	270 J	140 J	200 J	74 J	38 J	—
Acenaphthene	380 U	--	--	--	--	37 J	--	--	--	--	--	29,000,000
Dibenzofuran	380 U	86 J	--	--	--	88 J	37 J	--	--	--	--	1,600,000
Fluorene	380 U	--	--	--	--	--	--	--	--	--	38 J	26,000,000
Phenanthrene	150 J	450	82 J	--	46 J	540	160 J	140 J	230 J	150 J	300 J	—
Anthracene	57 J	270 J	55 J	--	--	940	250 J	100 J	140 J	71 J	87 J	100,000,000
Fluoranthene	630	1800	850	99 J	120 J	3200	980	780	1400	480	450	22,000,000
Pyrene	640	1700	1100	110 J	140 J	3200	1000	890	1500	500	340 J	29,000,000
Benzo(a)Anthracene	620	1100	400	69 J	91 J	**2200**	570	500	920	320 J	190 J	2,100
Chrysene	**620**	**1700**	**710**	100 J	140 J	**3000**	**980**	**780**	**1300**	**470**	**240 J**	210
Benzo(b)Fluoranthene	550	1800	730	120 J	170 J	**3200**	1200	1000	1400	570	230 J	2,100
Benzo(k)Fluoranthene	460	1200	490	110 J	150 J	2500	800	670	1100	430	210 J	21,000
Benzo-a-Pyrene	**610**	**1100**	**390**	88 J	120 J	**2200**	**670**	**550**	**840**	**400**	190 J	210
Indeno (1,2,3-cd) Pyrene	370 J	900	330 J	67 J	100 J	2000	610	480	690	320 J	140 J	2,100
Dibenzo(a,h)Anthracene	80 J	**340 J**	100 J	--	--	**730**	86 J	180 J	**240 J**	110 J	57 J	210
Benzo(ghi)Perylene	210 J	660	220 J	55 J	100 J	1600	400	260 J	350	200 J	98 J	—
Phenol	380 U	43 J	--	--	--	--	--	--	--	--	--	100,000,000
Carbazole	380 U	200 J	55 J	--	--	340 J	110 J	49 J	65 J	42 J	43 J	86,000
Pesticides /PCBs (µg/kg)												
Aldrin	5.8 UJ	--	--	--	--	--	--	--	--	--	--	100

TABLE 4
SURFACE SOIL SAMPLE RESULTS

Analyte	Back-Ground BUF-01-SS	On Site Florida Smelting Company, Buffalo Avenue BUF-02-SS	BUF-03-SS	BUF-04-SS	BUF-05-SS	BUF-06-SS	BUF-07-SS	BUF-08-SS	BUF-21-SS[a]	BUF-09-SS	BUF-10-SS	Guidance PRG[b]
Heptachlor Epoxide	5.3 UJ	--	--	--	--	--	--	--	--	--	--	190
gamma-BHC (Lindane)	4.5 UJ	--	--	--	--	--	--	--	--	--	--	—
Endosulfan I (alpha)	18 UJ	--	--	--	--	--	--	--	--	--	--	3,700,000
Dieldrin	6.7 UJ	--	--	--	--	--	--	--	--	--	--	110
4,4'-DDT (p,p'-DDT)	24 UJ	--	--	--	--	--	--	--	--	--	--	7,000
Endosulfan II (beta)	12 UJ	--	--	--	--	--	--	--	--	--	--	3700000
PCB-1254 (Aroclor 1254)	57 U	--	--	450	110	--	--	--	--	--	--	740
PCB-1260 (Aroclor 1260)	23 J	18 J	--	--	--	49 J	--	--	--	--	--	740
gamma-Chlordane /2	9.6	--	--	--	--	--	--	--	--	--	--	6,500
trans-Nonachlor /2	19 U	--	--	--	--	--	--	--	--	--	--	—
alpha-Chlordane /2	20 U	--	--	7.9 J	--	--	--	--	--	--	--	6,500
Methoxychlor	26 UJ	--	--	--	--	--	--	--	--	--	--	3,100,000

Notes: Shaded cells represent elevated concentrations compared to background; bold values represent concentrations exceeding guidance value.
- a Duplicate sample
- b EPA Region 9 Preliminary Remediation Goal for industrial soil
- J Estimated value
- R Data rejected
- U Substance was analyzed for but not detected; value listed is the Minimum Quantitation Limit
- µg/kg Micrograms per kilogram
- mg/kg Milligrams per kilogram
- -- Sample was not analyzed
- — No value determined

TABLE 4 (Continued)
SURFACE SOIL SAMPLE RESULTS

Analyte	Back-Ground	On Site: Florida Smelting Company, Buffalo Avenue											Guidance PRG[b]
	BUF-01-SS	BUF-11-SS	BUF-22-SS[a]	BUF-12-SS	BUF-13-SS	BUF-14-SS	BUF-15-SS	BUF-16-SS	BUF-17-SS	BUF-18-SS	BUF-19-SS	BUF-20-SS	
Metals (mg/kg)													
Arsenic	**3.9 J**	**6.5 J**	**7.1 J**	**5.4 J**	**2.3 J**	**21 J**	**5.4 J**	0.68 J	--	**4.5 J**	**3.2 J**	**2.7 J**	1.6
Barium	84 J	8.8 J	--	14 J	7.0 J	52 J	39 J	6.9 J	7.5 J	7.1 J	11 J	11 J	67,000
Beryllium	0.07 UJ	--	--	--	--	0.63	--	--	--	--	--	--	1,900
Cadmium	0.63 J	0.14 J	0.16 J	0.25 J	0.06 R	0.83 J	0.93 J	0.06 J	0.09 J	0.10 J	0.19 J	0.15 J	450
Cobalt	1.2 J	0.51 J	0.34 J	0.51 J	0.21 J	1.2 J	1.4 J	0.15 J	0.21 J	0.23 J	0.32 J	0.45 J	1,900
Chromium	12 J	3.4 J	3.8 J	8.5 J	2.3 J	11 J	11 J	3.0 J	2.6 J	2.7 J	4.0 J	4.0 J	450
Copper	28 J	7.3 J	6.4 J	4.2 J	3.1 J	24 J	13 J	2.0 J	1.9 J	2.6 J	13 J	9.0 J	41,000
Nickel	5.8 J	1.7 J	1.8 J	--	--	7.0 J	6.4 J	--	--	--	--	--	20,000
Lead	92 J	170 J	200 J	90 J	68 J	**1100 J**	580 J	120 J	98 J	160 J	**2000 J**	260 J	800
Antimony	6.9 UJ	2.3 J	2.5 J	--	--	1.9 J	4.3 J	--	--	0.76 R	69 J	1.8 J	410
Thallium	2.9 U	--	--	--	--	0.75 J	--	--	--	--	--	--	67
Vanadium	8.3 J	4.2 J	4.7 J	8.7 J	3.1 J	12 J	24 J	3.0 J	3.9 J	3.9 J	5.8 J	7.9 J	1,000
Zinc	180 J	31 J	35 J	23 J	35 J	86 J	130 J	14 J	23 J	23 J	45 J	33 J	100,000
Total Mercury	0.06 UJ	--	--	--	--	0.13	--	--	--	--	--	--	310
Aluminum	2200 J	2000 J	2400 J	2700 J	1500 J	4300 J	6000 J	1900 J	2500 J	2100 J	2700 J	2100 J	100,000
Manganese	81 J	19 J	16 J	24 J	8.6 J	160 J	47 J	7.9 J	10 J	12 J	14 J	21 J	19,000
Magnesium	860 J	200 J	270 J	1100 J	180 J	1300 J	350 J	120 J	110 J	400 J	280 J	330 J	—
Iron	10000	2500	1900	1500	900	10000	3600	900	1000	1200	1400	1700	100,000
Volatiles (µg/kg)													
Acetone	12 UJ	--	--	--	--	--	--	--	--	--	--	--	54,000,000
Methyl Ethyl Ketone	12 UJ	--	--	--	--	--	--	--	--	--	--	--	110,000,000
Semi-volatiles (µg/kg)													
Acetophenone	380 U	--	--	--	--	--	--	--	--	--	--	--	—
1,1-Biphenyl	380 U	--	--	--	--	--	--	--	--	--	54 J	--	23,000,000
2-Methylnaphthalene	380 U	62 J	48 J	--	--	66 J	72 J	--	--	--	450	71 J	—
Naphthalene	380 U	--	--	--	--	60 J	59 J	--	--	--	190 J	--	190,000
Acenaphthylene	120 J	73 J	74 J	--	--	210 J	--	--	--	--	--	--	—
Acenaphthene	380 U	--	--	--	--	--	--	--	--	--	--	--	29,000,000
Dibenzofuran	380 U	--	--	--	--	--	--	--	--	--	--	--	1,600,000
Fluorene	380 U	--	--	--	--	--	--	--	--	--	--	--	26,000,000
Phenanthrene	150 J	54 J	49 J	--	--	210 J	280 J	91 J	--	--	87 J	60 J	—
Anthracene	57 J	82 J	95 J	--	--	260 J	56 J	--	--	--	--	--	100,000,000
Fluoranthene	630	220 J	200 J	77 J	110 J	1300	610	230 J	75 J	68 J	88 J	130 J	22,000,000
Pyrene	640	260 J	220 J	85 J	160 J	1400	500	190 J	68 J	84 J	91 J	170 J	29,000,000
Benzo(a)Anthracene	620	220 J	180 J	62 J	120 J	1100	280 J	110 J	41 J	48 J	58 J	110 J	2,100
Chrysene	**620**	**300 J**	**280 J**	92 J	180 J	**1400**	**370**	120 J	48 J	62 J	86 J	160 J	210
Benzo(b)Fluoranthene	550	350	320 J	100 J	190 J	1700	370	98 J	52 J	64 J	80 J	200 J	2,100
Benzo(k)Fluoranthene	460	300 J	310 J	91 J	120 J	1200	240 J	100 J	40 J	55 J	70 J	150 J	21,000
Benzo-a-Pyrene	**610**	**250 J**	**230 J**	74 J	110 J	**1200**	**310 J**	110 J	51 J	51 J	78 J	130 J	210
Indeno (1,2,3-cd) Pyrene	370 J	230 J	220 J	60 J	75 J	810	220 J	74 J	--	--	49 J	93 J	2,100
Dibenzo(a,h)Anthracene	80 J	100 J	--	--	--	**320 J**	81 J	--	--	--	--	--	210
Benzo(ghi)Perylene	210 J	170 J	150 J	--	42 J	510	140 J	44 J	--	--	43 J	52 J	—
Phenol	380 U	--	--	--	--	--	--	--	--	--	--	--	100,000,000
Carbazole	380 U	34 J	35 J	--	--	120 J	44 J	--	--	--	--	--	86,000
Pesticides /PCBs (µg/kg)													
Aldrin	5.8 UJ	--	--	--	--	--	--	--	--	--	--	--	100
Heptachlor Epoxide	5.3 UJ	--	--	--	--	--	--	--	--	--	--	--	190
gamma-BHC (Lindane)	4.5 UJ	--	--	--	--	--	--	--	--	--	--	--	—
Endosulfan I (alpha)	18 UJ	--	--	--	--	--	--	--	--	--	--	--	3,700,000

TABLE 4 (Continued)
SURFACE SOIL SAMPLE RESULTS

Analyte	Back-Ground	On Site											Guidance
		Florida Smelting Company, Buffalo Avenue											PRG[b]
	BUF-01-SS	BUF-11-SS	BUF-22-SS[a]	BUF-12-SS	BUF-13-SS	BUF-14-SS	BUF-15-SS	BUF-16-SS	BUF-17-SS	BUF-18-SS	BUF-19-SS	BUF-20-SS	
Dieldrin	6.7 UJ	--	--	--	--	--	--	--	--	--	--	--	110
4,4'-DDT (p,p'-DDT)	24 UJ	--	--	--	--	--	--	--	--	--	--	--	7,000
Endosulfan II (beta)	12 UJ	--	--	--	--	--	--	--	--	--	--	--	3700000
PCB-1254 (Aroclor 1254)	57 U	--	150	--	--	--	--	--	--	--	--	--	740
PCB-1260 (Aroclor 1260)	23 J	--	--	--	--	110	35 J	--	--	--	120	--	740
gamma-Chlordane /2	9.6	1.6 J	--	--	--	2 J	--	--	--	--	--	--	6,500
trans-Nonachlor /2	19 U	--	--	--	--	4.2 J	--	--	--	--	--	--	—
alpha-Chlordane /2	20 U	--	--	--	--	--	--	--	--	--	--	--	6,500
Methoxychlor	26 UJ	--	--	--	--	--	--	--	--	--	--	--	3,100,000

Notes: Shaded cells represent elevated concentrations compared to background; bold values represent concentrations exceeding guidance value.
- a Duplicate sample
- b EPA Region 9 Preliminary Remediation Goal for industrial soil
- J Estimated value
- R Data rejected
- U Substance was analyzed for but not detected; value listed is the Minimum Quantitation Limit
- µg/kg Micrograms per kilogram
- mg/kg Milligrams per kilogram
- —— Sample was not analyzed
- — No value determined

TABLE 5
SUBSURFACE SOIL SAMPLE RESULTS

Analyte	Back-Ground	On site					Guidance
		Florida Smelting Company, Buffalo Avenue					PRG[b]
	BUF-01-SB	BUF-02-SB	BUF-03-SB	BUF-04-SB	BUF-05-SB	BUF-06-SB[a]	
Metals (mg/kg)							
Arsenic	0.63 R	**7.6 J**	**3.7 J**	**3.5 J**	**11 J**	**15 J**	1.6
Barium	3.5 J	3.1 J	2.4 J	9.4 J	11 J	15 J	67,000
Beryllium	0.01 UJ	--	--	--	--	--	1,900
Cadmium	0.53 U	--	--	0.13 R	0.45 J	0.64 J	450
Cobalt	0.08 J	0.14 R	--	0.29 J	0.35 J	1.1 J	1,900
Chromium	1.4 J	1.2 J	1.1 J	4.9 J	4.3 J	9.5 J	450
Copper	0.20 J	--	--	15 J	10 J	16 J	41,000
Nickel	0.65 UJ	--	--	--	2.1 J	7.4 J	20,000
Lead	2.5 J	1.1 J	0.94 J	**840 J**	590 J	**1100 J**	800
Antimony	6.4 UJ	--	--	12 J	8.2 J	17 J	410
Vanadium	1.3 J	1.1 J	0.91 J	4.5 J	4.8 J	4.9 J	1,000
Zinc	4.8 UJ	--	--	79 J	38 J	55 J	100,000
Aluminum	970 J	1100 J	820 J	3600 J	2400 J	2600 J	100,000
Manganese	2.4 J	4.1 J	2.8 J	9.3 J	17 J	32 J	19,000
Magnesium	54 J	42 J	31 J	150 J	360 J	160 J	—
Iron	320	440	310	1500	2000	7700	100,000
Volatiles (µg/kg)							
Acetone	11 UJ	--	--	35	--	--	54,000,000
Methyl Ethyl Ketone	11 UJ	--	--	--	--	--	110,000,000
Semi-volatiles (µg/kg)							
2-Methylnaphthalene	350 U	--	--	--	41 J	41 J	—
Acenaphthylene	350 U	--	--	--	120 J	120 J	—
Phenanthrene	350 U	--	--	--	74 J	65 J	—
Anthracene	350 U	--	--	--	140 J	150 J	100,000,000
Fluoranthene	350 U	--	--	57 J	460	450	22,000,000
Pyrene	350 U	--	--	79 J	500	520	29,000,000
Benzo(a)Anthracene	350 U	--	--	49 J	350	390	2,100
Chrysene	350 U	--	--	73 J	**500**	**510**	210
Benzo(b)Fluoranthene	350 U	--	--	110 J	630	670	2,100
Benzo(k)Fluoranthene	350 U	--	--	70 J	460	410	21,000
Benzo-a-Pyrene	350 U	--	--	75 J	**410**	**420**	210
Indeno (1,2,3-cd) Pyrene	350 U	--	--	54 J	340 J	360	2,100
Dibenzo(a,h)Anthracene	350 U	--	--	--	160 J	180 J	210
Benzo(ghi)Perylene	350 U	--	--	48 J	320 J	350 J	—
Carbazole	350 U	--	--	--	52 J	52 J	86,000
Pesticides /PCBs (µg/kg)							
Aldrin	4.2 UJ	--	--	--	--	--	100
Heptachlor Epoxide	4.2 UJ	--	--	--	--	--	190
gamma-BHC (Lindane)	4.2 UJ	--	--	--	--	--	—
Endosulfan I (alpha)	4.2 UJ	--	--	--	--	--	3,700,000
Dieldrin	4.2 UJ	--	--	--	--	--	110
4,4'-DDT (p,p'-DDT)	6 J	--	--	--	--	--	7,000
Endosulfan II (beta)	11 UJ	--	--	--	--	--	3,700,000
PCB-1254 (Aroclor 1254)	53 U	--	--	460	--	--	740
PCB-1260 (Aroclor 1260)	53 U	--	--	--	38 J	63 J	740
alpha-Chlordane /2	4.2 U	--	--	8.1 J	--	1.1 J	6,500
Methoxychlor	21 UJ	--	--	--	--	--	3,100,000

Notes: Shaded cells represent elevated concentrations compared to background; bold values represent concentrations exceeding guidance value.

a Duplicate sample

b EPA Region 9 Preliminary Remediation Goal for industrial soil

J Estimated value

R Data rejected

U Substance was analyzed for but not detected; value listed is the Minimum Quantitation Limit

µg/kg Micrograms per kilogram

mg/kg Milligrams per kilogram

— — Sample was not analyzed

— No value determined

TABLE 6

FLORIDAN AQUIFER GROUNDWATER RECEPTORS

Distance / Radius Ring	Municipal/Community Water System	Number of Active Wells	Population per Well	Total Population per Wellfield	Total Population Served per Radial Distance
0–0.25 Mile	--	--	--	--	--
0.25–0.5 Mile	--	--	--	--	--
0.5–1 Mile	--	--	--	--	--
1–2 Miles	Norwood (North Grid) Woodmere	4 2	8,957 1,522	35,828 3,044	38,872
2–3 Miles	Lake Forrest Woodmere Jacksonville University Main Street (North Grid) McDuff (North Grid) Lake Lucina (South Grid)	1 1 3 5 1 1	2,108 1,522 283 8,957 8,957 8,810	2,108 1,522 849 44,785 8,957 8,810	67,031
3–4 Miles	Magnolia Gardens Main Street (North Grid) McDuff (North Grid) Arlington (South Grid) Lake Lucina (South Grid)	1 4 7 3 2	1,760 8,957 8,957 8,810 8,810	1,760 35,828 62,699 26,430 17,620	144,337

Notes:

Populations per well were derived from FDEP Drinking Water Facility Reports and JEA water plant summaries. Numbers of wells per wellfield and well locations were derived from FDEP provided topographic map and JEA geographic coordinates.

-- No wells or associated population in this radius ring.

Appendix C

Photographs

OFFICIAL PHOTOGRAPH No. 1
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	View of the site from Buffalo Avenue. Tanks seen to the right are on the Support Terminals/Kanab property and are not part of the site.
Date:	June 15, 2005 **Photographer:** Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 2
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of background soil samples BUF-01-SS and -01-SB. Samples were collected next to red truck seen on the right
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 3
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location: FSC Buffalo Site
EPA ID No. FLN000407555
Jacksonville, Duval County, Florida

Subject: Location of soil samples -02-SS and -02-SB located north of the railroad tracks. Vegetation was dense north of the railroad tracks.

Date: June 15, 2005 **Photographer:** Jorge Sanchez

Source: T N & Associates, Inc. – Superfund Technical Assessment Team
Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 4
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil samples -03-SS and -03-SB located north of the railroad tracks. Vegetation was dense north of the railroad tracks.
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 5
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil samples -04-SS and -04-SB located south of the railroad tracks. Soil was sandy south of the railroad tracks and vegetation was sparse.
Date:	June 15, 2005 **Photographer:** Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 6
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil samples -05-SS and 05-SB located south of the tracks. Tanks seen in the background are on the Support Terminals/Kanab property and are not part of the site.
Date:	June 15, 2005 **Photographer:** Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 7
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location: FSC Buffalo Site
EPA ID No. FLN000407555
Jacksonville, Duval County, Florida

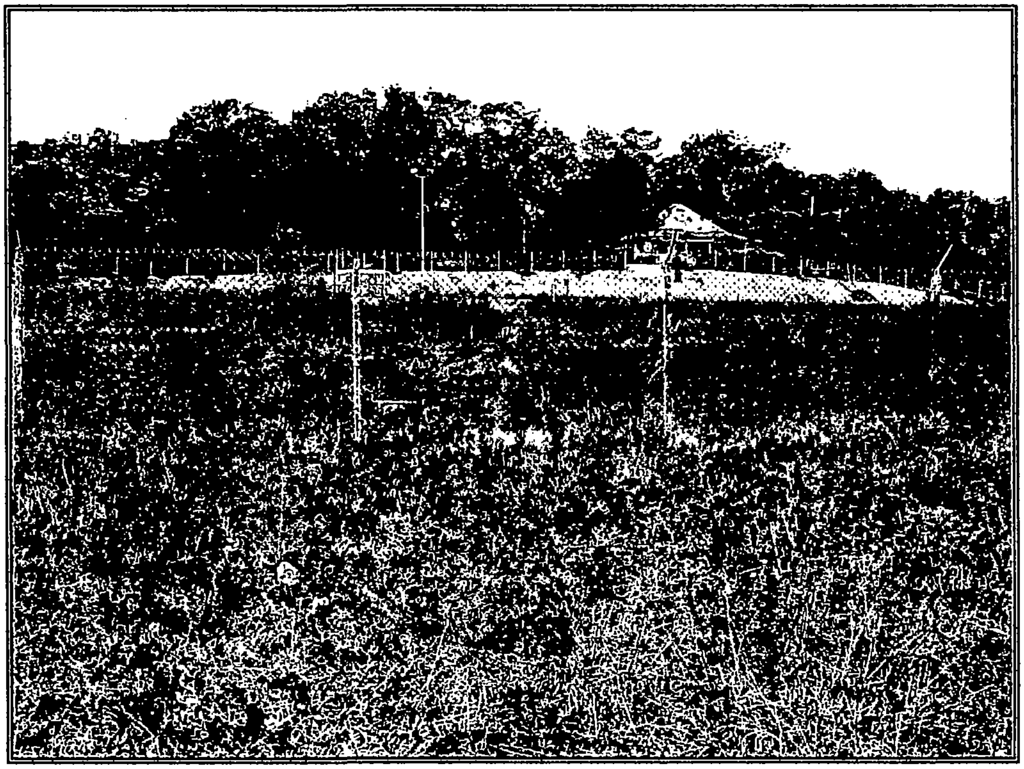
Subject: Location of soil samples -06-SS located in the northwest corner of site. Buffalo Avenue is located to the right.

Date: June 15, 2005 **Photographer:** Jorge Sanchez

Source: T N & Associates, Inc. – Superfund Technical Assessment Team
Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 8
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida		
Subject:	Location of soil sample -07-SS located north of the railroad tracks. Vegetation was dense north of the railroad tracks.		
Date:	June 15, 2005	**Photographer:**	Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event		



OFFICIAL PHOTOGRAPH No. 9
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -08-SS located north of the railroad tracks. The fence line separates the site from a former bulk fuel storage facility.
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 10
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -10-SS located north of the railroad tracks in the northeast corner of site.
Date:	June 15, 2005 Ph walski
Source:	T N & Associates, Inc. – Superfu Preliminary Assessment/Site Insp

Removal?

OFFICIAL PHOTOGRAPH No. 11
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location: FSC Buffalo Site
EPA ID No. FLN000407555
Jacksonville, Duval County, Florida

Subject: Location of soil sample -10-SS located south of the tracks.
The Support Terminals/Kanab property can be seen beyond the fence.
Buffalo Avenue is located to the right.

Date: June 15, 2005 **Photographer:** Greg Kowalski

Source: T N & Associates, Inc. – Superfund Technical Assessment Team
Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 12
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil samples -12-SS located south of the railroad tracks. Support Terminals/Kanab can be seen beyond the fence.
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 13
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -13-SS located south of the railroad tracks in the southeast corner of site.
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 14
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -14-SS located west of Buffalo Avenue. Buffalo Avenue can be seen in the background.
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 15
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location: FSC Buffalo Site
EPA ID No. FLN000407555
Jacksonville, Duval County, Florida

Subject: Location of soil sample -15-SS collected near the tree line in front of the truck.

Date: June 15, 2005 **Photographer:** Greg Kowalski

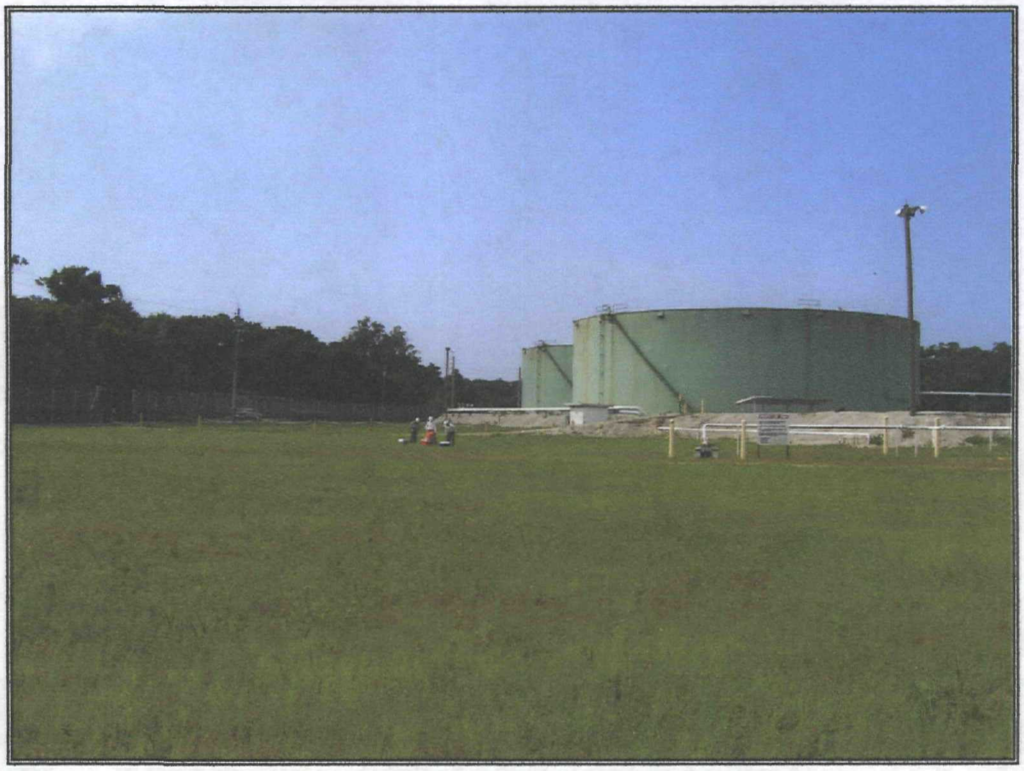
Source: T N & Associates, Inc. – Superfund Technical Assessment Team
Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 16
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -16-SS collected in the northwest corner of the Support Terminals/Kanab property.
Date:	June 15, 2005 **Photographer:** Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 17
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil samples -17-SS collected in the northwest portion of the Support Terminals/Kanab property.
Date:	June 15, 2005 **Photographer:** Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event



OFFICIAL PHOTOGRAPH No. 18
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location: FSC Buffalo Site
EPA ID No. FLN000407555
Jacksonville, Duval County, Florida

Subject: Location of soil sample -18-SS collected in the northeast portion of the Support Terminals/Kanab property.

Date: June 15, 2005 **Photographer:** Jorge Sanchez

Source: T N & Associates, Inc. – Superfund Technical Assessment Team
Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 19
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida
Subject:	Location of soil sample -19-SS collected in the northeast corner of the Support Terminals/Kanab property (on the lawn area behind the fence).
Date:	June 15, 2005 **Photographer:** Jorge Sanchez
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event

OFFICIAL PHOTOGRAPH No. 20
U.S. ENVIRONMENTAL PROTECTION AGENCY

Location:	FSC Buffalo Site EPA ID No. FLN000407555 Jacksonville, Duval County, Florida		
Subject:	Location of soil sample -20-SS collected in the north-central portion of the Support Terminals/Kanab property.		
Date:	June 15, 2005	**Photographer:**	Greg Kowalski
Source:	T N & Associates, Inc. – Superfund Technical Assessment Team Preliminary Assessment/Site Inspection field sampling event		

Appendix D

Log Notes

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

LEVEL

All-Weather Notebook
No. 311

Fla. Smelting Co.-Buffalo (FSC Buffalo)
Jacksonville, Duval Co., Florida
EPA ID FLN000407555
Logbook #1

4 5/8" x 7" - 48 Numbered Pages

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

INCHES 1 2 3 4 5 6

Name ______________________________

____

Address ______________________________

____

Phone ______________________________

Project ______________________________

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CONTENTS

PAGE	REFERENCE	DATE

April 11, 2003

Travel To Jax, Fla. To View Several Sites That The Assoc. (TNLA) Will Be Collecting Samples From, Incl. The Florida Smelting Company - Buffalo Ave. Site (FSC Buffalo). FSC Buffalo Exists In An Urban, Industrial Area With Residential Areas To The North & South Approx. 1/4 Mile Away. The St. Johns River Is ~1/3 Mile To The East, & The Trout River Is ~1/2 Mile To The North. Bulk Fuel Storage Tank Farms Are Located To The Northeast & Southeast. The Old FSC Buffalo Site Appears To Exist On The Northwest Corner Of A Bulk Fuel Storage Area Containing 2 Large (500,000 gal.+) Storage Tanks On The Southeast Portion Of Site. Evergreen Ave Borders The Storage Area On The East. Fencing Surrounds The Storage Area Property (6' Chain Link w/ Barb-wire). A Railroad Spur Is Located Next To Site To The North, & May Actually Be Part Of The Historic FSC Buffalo Site. This Spur Is Also Fenced As Part Of The Facility North Of Site. Several (~4) Additional Above Ground Storage Tanks (10,000-50,000 gal.) Were Observed On This Site, Which Is Also Fenced. RR Tracks Exist To The North Of This Facility Also.

4/11/03 Cont.

3

No Drainage Features Were Observed Leaving Site. A Large Sewer Grate Was Observed On The Eastern Portion Of The Storage Facility, ~10 Feet East Of Buffalo Ave., Near The Entrance Road/Driveway. The Storage Facility Also Had Several Covered Bays For Filling Tanker Trucks Located Near The Center Of Site. A Small Bldg. Was Located To The Southeast Of The Loading Bays. One Horizontal Tank (Poss. Propane or LNG) Was Located Along The Northern Edge Of The Storage Facility, Where It Is Believed That FSC Buffalo Once Existed. A Tall, Slender Tank (Unk.) Is Also In This Area. Transfer Lines Go From This Area, Over The Fencing & RR Tracks, To The Facility To The North.

[signature]

2004 - 2005

Access Issues Delay Field Sampling Event. Kanab & CSX Disagree On The Location Of The Former FSC Structure. Both Parties Eventually Permit Access - Kanab Will Split Samples From Their Property. CSX Only Requests Notification Of When Sampling Will Occur.

June 15, 2005

0800 Arrive At FSC Buffalo Ave Site. Hold Safety Mtg: Threats Are Trains, Slip/trip, Heat Exhaustion.

0900 Meet With Dylan Morgan & David Dixon At The Main Support Terminals Facility At 6531 Buffalo. Hold Safety Mtg/Briefing.

0950 Collect Sampling Equip & Head Inside Terminal Property To Sample. Sampling Team In Terminal Is K. Patten & J. Sanchez Accompanied With Dylan Morgan & David Dixon (Coastal).

1007 Collect Soil Sample 16-SS. Split With Kanab. See Logbook 2 For Details.

1025 Collect Soil Sample 17-SS Split With Kanab.

SS-16 Located 4 yds South Of Rail Post. & 3 yds East Of Western Fence.

17-SS Located 150' NNW Of N. Gate.

1043 Collect 18-SS @ Kanab. Sample Was Relocated Since Original Location Was Within Secondary Containment Area Of Gasoline Tanks.

June 15, 2005

New Loc. Moves SS 18 East To SS-19 Loc. SS 19 Moves NW & SS-20 Moves NE.

1100 Collect SS-19 100' West Of Evergreen Fencing, 50' South Of Northern Fencing

1125 Collect SS-20 @ Kanaks Collected 60' East Of Center Of Bldg.

1140 Return To Staging Area & Begin To Secure For Lunch Break. Samples Remain On Ice.

1200 Break For Lunch

1300 Return To Site & Prepare To Collect Soil Samples. Team 1 Consists Of G. Kowalski; Team 2 Is K. Patton & J. Sanchez (See Logbook 2).

1350 Collect 09-SS / No Splits From CSX Prop. Sample Is 30' North Of Tracks, 100' West Of Evergreen. Soil Type Is A Black Sand Topsoil With Grey Sand. Vegetation Is Brown/Dry To South & Green (Different Type To North).
GPS: 30° 22' 39.9" N, 81° 38' 19.5" W.

1415 Collect Soil 08-SS & Dupe 21-SS From Same Loc 35' N of Tracks, 10' West Of Eastern Track Switch, 20' South Of Fence.
GPS: 30° 22' 39.8" N, 81° 38' 21.2" W

Soil Type Is A Black Top Soil W/ Grey Sand. Normal Veg.

1445 Collect SS-13 Near Vegetated Area At East Side Of Site, 15' North Of Fence At Kanaks. Debris Located In Veg. Area (Boat, A/C, Tires, Metal Scrap) Soil Type Is A Grey Sand. Vegetation Is Sparse On South Side Of Tracks.
GPS: 30° 22' 38.4" N, 81° 38' 21.0"

1515 Begin Processing Samples For Shipment.

1700 One Team Heads To UPS With All Samples Collected Today. Second Team Heads To Purchase New Printer. End Of Day.

June 16, 2005
Cond: Hot, Humid, 85-95
0800 Arrive At Site & Set Up.
No Consultants On Site From CSX.
All Remaining Samples Are From CSX Prop.
0820 Collect 05-SS 20' North Kanab Fence,
30' South Of RR Tracks. Soil Type
Is A Moist Grey Sand / No Organics.
No / Sparse Vegetation In This Area.
See Logbook 2 For GPS Loc. Of
02-05-SS Samples
0840 Collect 04-SS 20' North Of Kanab
Fence, In Line With Fire Hydrant
Soil Type Is A Grey Sand. Vegetation
Is Sparse. Loc Is ~150 East Of Buffalo Ave.
No Observations Of Interest (No Footings,
Concrete Pads, Or Other Items To Support
A Building Was Located Here.
0900 Collect 02-SS 25' North Of Tracks
In Line With Fire Hydrant (Due North Of 04)
~150' East Of Buffalo Ave. Vegetation
Is Present Here And Appears Healthy.
Soil Type Is A Thin Layer Of Black Grey
Top Soil (1") With Grey Sand Beneath.
No Signs / Observations Of Former Bldg.

6/16/05
0915 Collect 03-SS 30' North Of
Tracks, North Of 05-SS, Due North
Of Center Of Tank Farm @ Kanab.
Thin Layer Of Top Soil (0.5") Covers
Grey Sand. Veg. Normal / Healthy.
0930 Troubleshoot Power Issues To
Laptop Computer (Won't Run w/ Auto
Power Source & Batt. Has Died.)
0955 Able To Remedy Computer Problem
& Continue Running FZZ.
1005 Collect SS-07 25' North Of
Tracks, 20' South Of Fence Corner
Of Phillips Prop. Veg. Is Normal
Soil Type Is Grey / Black Sand, Slightly
Rocky Intermixed.
GPS: 30° 22' 39.7" N, 81° 38' 24.0" W
This Area Slightly More Rocky / Gravel
Than Other Areas.
Loc Is Due North Of Western Edge
Of Bldg @ Kanab.
1020 Collect 11-SS & Dup 22-SS From
30' North Of Kanab Fence, Along
In Line With Western Edge Of Bldg.
Soil Type Is A Grey Sand, Veg Is
Sparse In This Sandy Area.

6/16/05

GPS: 30° 22' 38.0"N, 81° 38' 24.0"W

1050 Begin Processing/Packing Samples For Shipment.

1210 Depart Site For Lunch.

1340 Arrive Back At Hotel & Determine Best Way To Keep Samples Cold In The Extreme Heat Is To Retain The Samples As Long As Possible, Then Relinquish Them To UPS To Avoid Having Them Sit In Hot Trucks Or On Loading Docks.

1700 Keep Samples At Hotel Then Have UPS Pick Up Between 1700-1800 (As Late As Can Be Scheduled)

End Of Field Sampling Event.

Fri. June 17, 2005

Sampling Team Demobilizes Back To Atlanta (Marietta); Cleans & Returns Rental Equipment And Rental Vehicles.

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

LEVEL

All-Weather Notebook
No. 311

Buffalo Ave Site (FSC Buffalo)

Florida Smelting Company
Jacksonville, Duval County, FL
U.S. EPA ID No. FLN000407555
KANEB Terminals

4 5/8" x 7" - 48 Numbered Pages

LogBook #2

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

Name Jorge A. Sanchez
Senior Project Chemist
Address 840 Kennesaw Ave. Suite B7
Marietta, Georgia 30060
Phone 678-355-5550

Project Florida Smelting Company
Jacksonville, Duval County, Florida
U.S. EPA ID. No. FL N000407555
KANEB Terminals.

Clear Vinyl Protective Slipcovers (Item No. 30) are available for this style of notebook. Helps protect your notebook from wear & tear. Contact your dealer or the J. L. Darling Corporation.

CONTENTS

6/16

06/15/05

07:30 Conducted Safety Tailgate Meeting.
- Stay clear off Rail Road Track.
- Watch for uneven grounds
- Drink plenty of fluids. Heat Exhaustion
- Slips, trips and falls.

08:15 Arrived at site area and set-up materials and equipment ready for sampling. Calibration of Field Analytical Equipment

Component	Concentration	Precalibration	Post Cal reading
Isobutylene	100 ppm	98.2 ppm	100 ppm
CO	50 ppm	80 ppm	53 ppm
VOC			
H_2S	25 ppm	21 ppm	25 ppm
LEL	50%	51%	50%
O^2	20.9%	20.6%	20.8%

weather High 95° F = Temperature
100% = Humidity
Conditions = Clear skies afternoon thunderstorms

09:00 Reported to Kaneb Terminals aka ST Services for signing in procedures and debriefing safety and security procedures. Mr. Dylan T. Morgan, P.G. Senior Manager - Environmental Remediation + Regulatory Oversight Health, Environment,

6/15/05

Safety + Security Division Kaneb conducted the safety briefing at the Terminal facility office. Dave Davidson with tag along for split samples.

09:40 Completed briefing with Kaneb Left office via set-up sampling area.

10:00 Inside the Tank Farm area near to commence sampling even on secure ground along with Kaneb officer.

10:07 Collecting Sample ID # 16-SS.
Location: Tank farm grassy area east of Buffalo Avenue. Fenced area. Across from 50th Street and Buffalo Avenue. West corner of Fenced area. (Next to rail Crossing) Exit from #2 trucks

GPS Coordinates - N 30° 22' 36.7"
W 081° 38' 27.3"

Soil Type: Silty Sandy Light Brown Soil.
Field Analytical: CO = 0 ppm LEL = 0%
VOC = 0.0 ppm O^2 = 20.8%
H_2S = 0 ppm

10:25 Collecting Sample ID# 17-SS.
Location: Tank farm grassy area east of Buffalo St And 50th Street Intersection. Next to (right) security Fence. Near gas Tank (propane bullet Tank)

6/15/05

GPS Coordinates N 30° 22' 36.2"

~~W 081° 26~~

W 081° 38' 26.0"

Soil Type: Silty Sandy Light Brown Soil

Field Analytical: CO = 0ppm, LEL = 0%

VOC = 0ppm, O^2 = 20.9%

H_2S = 0ppm

10:43 Collecting Sample ID # 18-SS

Location. East grassy area. West from Evergreen Avenue. North-East from AST.

GPS Coordinates N 30° 22 36.2"

W 081° 38' 20.1"

Soil Type: Silty Sandy Light Brown Soil.

Field Analytical: CO = 0ppm, LEL = 0%

VOC = 0ppm, O^2 = 20.9%

H_2S = 0ppm

11:00 Collecting Sample ID # 19-SS

Location: North end grassy area. West from Evergreen Road + East (far East) from Annex I Warehouse, About 15 yards from North Fence.

GPS Coordinates N 30° 22' 37.9"

W 081° 38' 20.1"

Soil Type Silty Sandy Light Brown Soil

Field Analytical CO = 0ppm, LEL = 1%

VOC = 0ppm O^2 = 20.9%

H_2S = 0ppm

6/15/05

11:23 Collecting Sample ID # 20-SS

Location: 20 yards East from ANNEX I Bldg. and about 15 yard South from North Fence Grassy area Parallell from ASTs.

GPS Coordinates N 30° 22' 38.0"

W 081° 38' 21.4"

Soil Type: Silty Sandy Light Brown Soil

Field Analytical: CO = 0.0ppm, LEL = 1%

VOC = 0.0ppm O^2 = 21.0%

H_2S = 0.0ppm

13:35 Collecting Sample ID # 01-SS.

Location: about 100 yards West of Buffalo Avenue. South from Rail Road tracks. Inside Openning Area from Tree Line. Shortcut through To 50th street.

GPS Coordinates. N 30° 22' 37.6"

W 081° 38' 33.5"

Soil Type: Silty Sandy Dark Brown Soil

Field Analytical: CO = 0ppm, LEL = 0%

VOC = 0.0ppm O^2 = 20.9%

H_2S = 0.0ppm

13:55 Collected Sample ID # 01-SB. Located at the same position from Sample ID# 01-SS.

Soil Type: Very fine Grain, (Sugar Sand), Sand Tan. Low

Photo Log

Photo #	Date	Site	Description
59	6/15/05	KAWEB	01SS/01SB East RR Track
60	"	"	01SS/01SB Tree Line South Box
61	"	"	15SS Between 50th Street + RR Track
62	"	"	~~#~~14SS West Buffalo Ave
63	"	"	12SS North Fence Corner ANNEX 1
64	"	"	13SS North Fence East ANNEX 1
65	"	"	08SS North RR Track
66	"	"	09SS North East RR T
67	6/16/05		05SB/06SB North East
68	"		04SS North East
69	"		04-SB "
70	"		02SS (Parallel to 04SS)
71	"		02SB "
72			03-SS (Parallel To 05-SS)
73			03-SB (Parallel To 05SB)
74			10-SS (Buffalo Ave)
75			06-SS (Between pine)
76			07SS (Parallel To 11-SS)
			11SS/22SS (North North West ANNEX 1)

moisture. Continue To auger to find saturated Sand and collect sample. Coordinates are the same as 01-SS and field analytical the same

14:07 Collecting Sample ID# ~~15~~ 15SS.

Location East of Buffalo Avenue between 50th Street and Rail Road Track. Inside Tree Line.

GPS Coordinates ~~N 30°22'38.3~~

N 30° 22' 36.3"

W 081° 38' 28.8"

Soil type Silty Sandy Brown Soil

Field Analytical CO = 0.0ppm, LEL = 0%

VOC = 0ppm · O^2 = 20.9%

H_2S = 0ppm.

14:45 Collecting Sample ID# 14SS.

Location West from Buffalo Avenue. 22 feet south from Rail Road Crossing Warning Lights.

GPS Coordinates N 30° 22' 38.5"

W 081° 38' 28.8"

Soil type: Silty Sandy Dark Brown soil

Field Analytical CO = 0.0ppm, LEL = 0%

VOC = 0.0ppm O^2 = 20.9%

H_2S = 0.0ppm

6/15, 16/05

15:05 Collecting Sample ID # 12SS.
Located North-North East from ANNEX 1 building 20' feet North from the Fence and 5' feet inside.
GPS Coordinates: N 30° 22' 38.6"
W 0 81° 38' 22.2"
Soil Type Silty Sandy Light Brown soil to Dark Brown Soil
Field Analytical: CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm O^2 = 20.9%
H_2S = 0.0ppm
17:45 Delivered 3 Sample coolers to UPS for overnight delivery to Analytical Lab.
18:10 Arrived at hotel Comfort Suites

06/16/05
07:00 Left hotel via site area CSX.
Conducted Tailgate safety meeting.
- Drink plenty of fluids keep hydrate
- Watch for uneven grounds and sharp objects.
- Watch for Railroad Traffic.
- Slips, trips + falls. Use proper bending technique to pick up materials.

08:00 Arrived at site area and began to set-up materials and equipment.
08:30 Collecting Sample ID # 05-SB
Located 15' feet North of Perimeter Fence and AST (Small ASTs) retaining dike
GPS Coordinates N 30° 22' 38.6"
W 081° 38' 25.6"
Soil Type Silty Sandy ~~Dark~~ Light Brown soil
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
In addition collected Duplicate Sample ID # 06-SB.
08:50 Collecting Sample ID# 04-SB
Location: East of Small AST farm. 15' feet North of Perimeter Fence. North of Fire Hydrant.
GPS Coordinates: N 30° 22' 38.6"
W 081° 38' 26.5"
Soil Type Silty Sandy ~~Dark~~ Light Brown Soil. Top layer consists of Sand white/Tan.
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
Weather: Temperature = Low 77°F high = 96°F
Humidity = 100%
Conditions: Partially cloudy. Sctd. Showers

Field Analytical: CO = 0.0ppm, H_2S = 0ppm
VOC = 0.0ppm, LEL = 0%, O^2 = 20.9%

6/16/05

09:10 Collecting Sample ID # 02-SB
Location Parallell To Sample ID # 04-SB
Across from Rail Road Track in between
the last Two Spurs.
GPS Coordinates N 30° 22' 39.6"
W 081° 38' 26.4"
Soil Type Silty Sandy Brown Soil
09:25 Collecting Sample ID # 03-SB
Location Parallell To Sample ID # 05-SB
North Rail Road tracks in between the
last Two Spurs
GPS Location N 30° 22' 39.7"
W 081° 38' 25.6"
Soil Type Silty Sandy Light tan, White Sand
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
09:55 Collecting Sample ID # 10-SS
Location. North-North West Corner of
KANEB Tank Farm Perimeter Fence.
Next to Buffalo Avenue (28' feet), and
18' feet Diagonal of Rail Road Crossing
Tracks 3 Warning Signal lights.
GPS Coordinates N 30° 22' 38.6"
W 081° 38' 28.0"

6/16/05

Soil Type: Silty Sandy Dark Brown
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
10:02 Collecting Sample ID # 06-SS
Location Parallell to Sample ID # 10-SS.
Between Last Two North Spurs.
25' Away from middle of Track on
each side of the Spur. In between
Two RailRoad Track Crossing #3 Warning
Lights for Buffalo Avenue, 50' feet
away or East of Buffalo Avenue
GPS Coordinates N 30° 22' 39.8"
W 081° 38' 28.1"
Soil Type Silty Sandy Brown Soil
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm

6/16/05

Appendix E

Analytical Data Sheets
(CD ROM)

Appendix E

Analytical Data Sheets
(CD ROM)

U.S. EPA REGION IV

SDMS

Unscannable Material Target Sheet

DocID: 10762859 Site ID: FLN000407555

Site Name: Florida Smelting Company (Buffalo)

Nature of Material:

Map:	☐	Computer Disks:	☐
Photos:	☐	CD-ROM:	☑
Blueprints:	☐	Oversized Report:	☐
Slides:	☐	Log Book:	☐

Other (describe) Laboratory Analytical (Appendix E)

Amount of material: ______

* Please contact the appropriate Records Center to view the material *

Reference 1

American Journal of Public Health, Vol 91, Issue 4 625-627, Copyright © 2001 by American Public Health Association

JOURNAL ARTICLE

Discovering unrecognized lead-smelting sites by historical methods

WP Eckel, MB Rabinowitz and GD Foster
Environmental Science-Public Policy Program, George Mason University, Fairfax, Va., USA. weckel@osf1.gmu.edu

OBJECTIVES: Our objective was to enumerate unrecognized former lead smelters in the United States. METHODS: Defunct smelters were identified by historical research. The compiled list was compared with government registries of hazardous sites. Soil samples were taken from 10 sites. RESULTS: Approximately 430 sites were unknown to the federal authorities. Only 5 of 319 sites were known to authorities in the top 8 states. Nine of the 10 sites sampled exceeded residential standards for soil lead level. CONCLUSIONS: Approximately 430 former lead-smelting sites were unrecognized in the United States. Sampling results indicate that the sites may pose a threat to public health.

Supplementary Material

Appendix A: Battery Lead Smelters

Appendix B: Babbitt Metal and Solders Smelters

Appendix A
"Battery Lead Smelter" Sites Apparently Unknown to Federal
And State Authorities

Site	Address	City	MSR
(State: Massachusetts, Region I)			
Harcon Corp.	41 Hilton St.	Boston	
Harcon Corp.	41 Bradston St.	Boston	
Vulcan Smelting Works	289 Third	Chelsea	
Richards Corp.	356 Commercial	Malden	
David Feinburg Co.	Fifth St.	Medford	plant
Arcade Smelting & Refining Corp.	--	Squantum	
(State: New Jersey, Region II)			
U.S. Metals Refining Co.	--	Carteret	equip
Magnolia Metal Co.	120 Bayway	Elizabeth	equip
Balbach Smelting & Refining Co.	Wilson & Doremus	Newark	plant
Barth Smelting Corp.	9 Fredon St.	Newark	
Eagle-Picher Lead Co.	--	Newark	
Hudson Smelting & Refining Co.	85-87 Hyatt Ave.	Newark	plant
Hudson Smelting & Refining Co.	576 Wilson Ave.	Newark	equip
Metal Reduction Corp.	4001 Dell Ave.	North Bergen	
Metals Disintegrating Co.	Morris Ave.	Townley	plant
(State: New York, Region II)			
City Metal Smelting & Refining Co.	61 N. 13th St.	Brooklyn	
Columbia Smelting & Refining Works	98 Lorraine	Brooklyn	
Consolidated Smelting	25 Provost Ave.	Brooklyn	
Fox & London Inc.	21 Provost St.	Brooklyn	
Glaser Lead Co.	21-31 Wyckoff Ave.	Brooklyn	
Kahn Bros. Smelting	785 Humboldt St.	Brooklyn	equip
Lee-Zurich Alloys Corp.	335 Calyer	Brooklyn	
United American Metals	970 Meeker St.	Brooklyn	
United American Metals	200 Diamond	Brooklyn	plant
Lake Erie Smelting Corp.	29 Superior	Buffalo	
Michael Hayman	856 E.Ferry	Buffalo	equip
National Lead	116 Oak	Buffalo	

Reliance Lead, Solder & Babbitt Co. Inc.	399 Gennessee St.	Buffalo	
Samuel Greenfield Co.	31 Stone	Buffalo	plant
Magnus Metals Div.	779 Walden Ave.	Depew	
Columbia Smelting & Refining Works Inc.	38-06 Review Ave.	Long Island City	
Goldsmith Bros. Smelting & Refining	43-20 12th St.	Long Island City	
Balbach Smelting & Refining Co.	63 Park Row	New York	
Duquesne Smelting Co.	18 E. 48th St.	New York	
Magnolia Metal Co.	75 West	New York	
Tottenville Copper Co.	Foot of W. 29th	New York	
A.M.A. Div.	P.O. Box 63	Oceanside	
A.M.A. Corp.	--	Rockville Centre	
Nassau Smelting & Refining Co.	603 W. 29th	Tottenville	plant

(State: Maryland, Region III)

Industrial Metal Melting	108 E. Barney	Baltimore	
Southern Smelting & Refining Works	200 Key Highway	Baltimore	plant

(State: Pennsylvania, Region III)

Hammond Lead Products	40 E. Main	Carnegie	
Schuylkill Valley Metals	--	Conshohocken	
Price Battery Corp.	--	Hamburg	
Penn Reduction & Refining Co.	--	New Castle	
American Alloys Co.	1939 E. Sargeant	Philadelphia	
Bers & Co.	Ashland & Lewis	Philadelphia	equip
Electric Storage Battery	42 S. 15th St.	Philadelphia	
Electric Storage Battery	19th & Allegheny	Philadelphia	
Girard Smelting & Refining Co.	Milnor & Bleigh Tacony Station	Philadelphia	plant
Halpern Metals Co.	5010 Lancaster Ave.	Philadelphia	
John T. Lewis & Bros.	2607 E. Cumberland	Philadelphia	
Jos. Rosenthal's Sons	1837 N. 2nd	Philadelphia	
Jos. Rosenthal's Sons	190-2 W. Berks St.	Philadelphia	
L. Goldstein's Sons Inc.	Wissinoming Ave. & Knorr	Philadelphia	equip
Ladenson Metals Co.	Castor Ave. E. of Richmond	Philadelphia	
Metro Smelting Co.	Ontario & Bath Sts	Philadelphia	
Morgan Smelters Inc.	Hedley St. E. of Richmond	Philadelphia	
Noth American Smelting	Tioga & Edgemont	Philadelphia	

Lead-Filled Lots

Study Says Potentially Toxic Sites Unlisted

By *Rose Palazzolo*
abcNEWS.com

April 3 — Hundreds of former lead smelting factory sites, some next to residential neighborhoods, could contain toxic levels of lead and no regulatory agency is aware of them, according to a new survey.

The study, released in the *American Public Health Journal*, cites 430 former lead smelting factories that are apparently not listed by the Environmental Protection Agency or local Health Departments.

"It's a potentially dangerous finding," said William Eckel, who conducted the study as part of his doctoral thesis at George Mason University in Fairfax, Va. He did the investigation in collaboration with his advisor, Gregory Foster and Michael Rabinowitz, a geochemist with the Marine Biological Laboratory in Woods Hole, Mass.

Potentially Hazardous Lead Levels in Soil

In the study, Eckel lists the sites of 640 former lead smelting factories in 35 states, which he says are filled with potentially hazardous levels of lead in the soil. Most of the sites are concentrated in industrial centers including Brooklyn, N.Y., Detroit, Baltimore, Los Angeles and Chicago. Eckel said he found the sites by looking in old industry directories and cross checked his findings with federal and state databases. He spent six years combing through the databases and books.

Lead smelting factories reclaim the lead in items such as car batteries and convert it back to pure lead and lead alloys. To counter the leeching of contaminants sites are either paved over or cleaned up by EPA officials. But Eckel claims that at least 430 or two-thirds of former lead smelting sites he identified were not known by the EPA or by State Departments of Health and therefore weren't paved over or cleaned up.

Although Eckel currently works at the Environmental Protection Agency, the EPA had nothing to do with his study and would not comment on the findings.

"It's impossible for us to comment on a study that we haven't even seen," said EPA spokesman Chris Paulitz. "Also, it is hard for us, as a new agency, to comment on what a previous agency [under former President Clinton] may or may not have done in terms of listing potential hazardous sites."

Potential For Great Lead Damage

Eckel, who now works at the pesticides division of the EPA, said that his study should send out an alarm. "If these sights are still contaminated and haven't been paved over there is potential for great lead damage here," he said.

While touring several sites in Pennsylvania and Baltimore Eckel noted that more than a few were just across from homes. One site was actually underneath an elevated section of a freeway next to the Orioles Stadium in Baltimore. When he tested these sites their lead levels exceeded those allowed by federal law for industrial sites and seven of the sites had levels exceeding the residential maximum.

"Not all the sites are necessarily contaminated, but they should all be checked out," Eckel said.

Large amounts of lead in a child's blood can cause brain damage, mental retardation, behavior problems, anemia, liver and kidney damage, hearing loss, hyperactivity, developmental delays and in extreme cases, death. There is new evidence that lead poisoning is harmful at blood levels once thought safe. Lower IQ scores, slower development and more attention problems have been observed in children with very low lead levels.

"Lead affects nearly every system of the body," says Barbara Materna, chief of the Occupational Lead Poisoning Prevention Program of the California Department of Health Services. Because it can cause so much damage, lead is the only environmental toxin for which children are routinely screened. Lead in the bloodstream can also lead to nerve damage and kidney failure and, in adults, infertility, miscarriages, and an inability to produce red blood cells.

The sites that Eckel found have as high as 10 percent lead by weight in soil. The EPA standard is 0.04 percent in residential areas and 0.1 percent in industrial areas. Some of the sites are in Boston, Buffalo, Chicago, Dallas, Detroit, Houston, Jersey City, Los Angeles, Newark, New York, Philadelphia, Pittsburgh, and San Francisco. ■

PRINT THIS PAGE SEND THIS TO A FRIEND

Site Determination:

[X] Enter the site into CERCLIS. Further assessment is recommended (explain below).

[ ] The site is not recommended for placement into CERCLIS (explain below).

DECISION/DISCUSSION/RATIONALE:

The following site was forwarded by EPA and discovered through an article in ABCNEWS.com.

Florida Smelting Company was located at 5801 Buffalo Avenue in Duval County, Jacksonville, Florida. The sites geographical coordinates are Latitude 30° 22' 38" N and Longitude 81° 38' 27" W. Earliest records indicate that the site began operating in 1950. Available sources show the operation continued until around 1960. The site is believed to be one of two that were operated under the name Florida Smelting Company. Some records imply that Florida Smelting Company operated at a 2726 Evergreen Avenue location until 1946, when the site became Albright and Company, Junk. In 1950 it appears that Florida Smelting Company began operations at the facility at 5800 Buffalo Avenue. The building is no longer located at the above stated address. Sanborn maps have clearly identified the former existence and location of the site. It is unclear what types of smelting operations were performed at the facility.

According to the Florida Department of Environmental Protection's Population Tiger Database, a total of 119,680 people live within four miles of the site. A review of the Florida Department of Environmental Protection's Potable Well System (PWS) database indicates that within four miles there are a number of municipal wells including the North Grid and South Grid municipal systems. An additional 6,558 individuals are served by sixteen other well systems within four miles of the site. The St. Johns River, located within one mile of the site is used extensively for recreational boating and swimming. It is also a migratory area for the federally endangered Shortnose Sturgeon and is a critical habitat for the Florida Manatee. A relatively large number of targets are nearby, including drinking water wells. Seven schools are located within two miles of the site.

Based on the fact that little is known about the former smelter, and the fact that smelting is often associated with high levels of metals and possibly solvents, there may be cause for concern at this site. The site is recommended for inclusion into CERCLIS and completion of a CERCLA Preliminary Assessment.

Regional EPA Reviewer: Wesley S. Hardegree / Wesley S Hardegree — 10/25/02
Print Name/Signature — Date

State Agency/Tribe: Teresa Kinner / [signature] — 10/21/02
Print Name/Signature — Date

U.S. EPA REGION IV

SDMS

Unscannable Material Target Sheet

DocID: 10762859 Site ID: FLN000407555

Site Name: Florida Smelting Company (Buffalo)

Nature of Material:

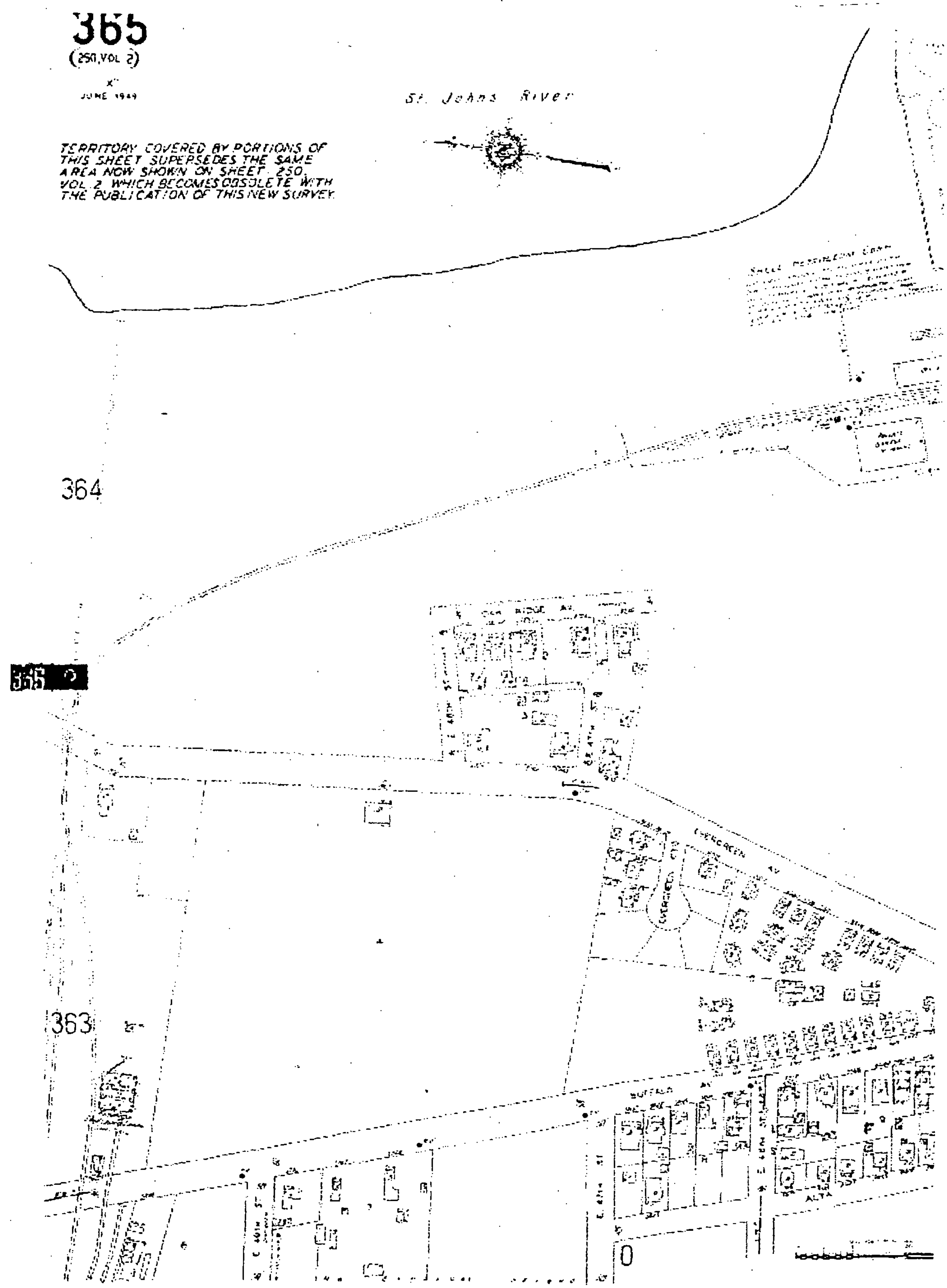
Map:	☐	Computer Disks:	☐
Photos:	☐	CD-ROM:	☐
Blueprints:	☐	Oversized Report:	☐
Slides:	☐	Log Book:	☐

Other (describe): Radius Map

Amount of material:

* Please contact the appropriate Records Center to view the material *

Reference 5



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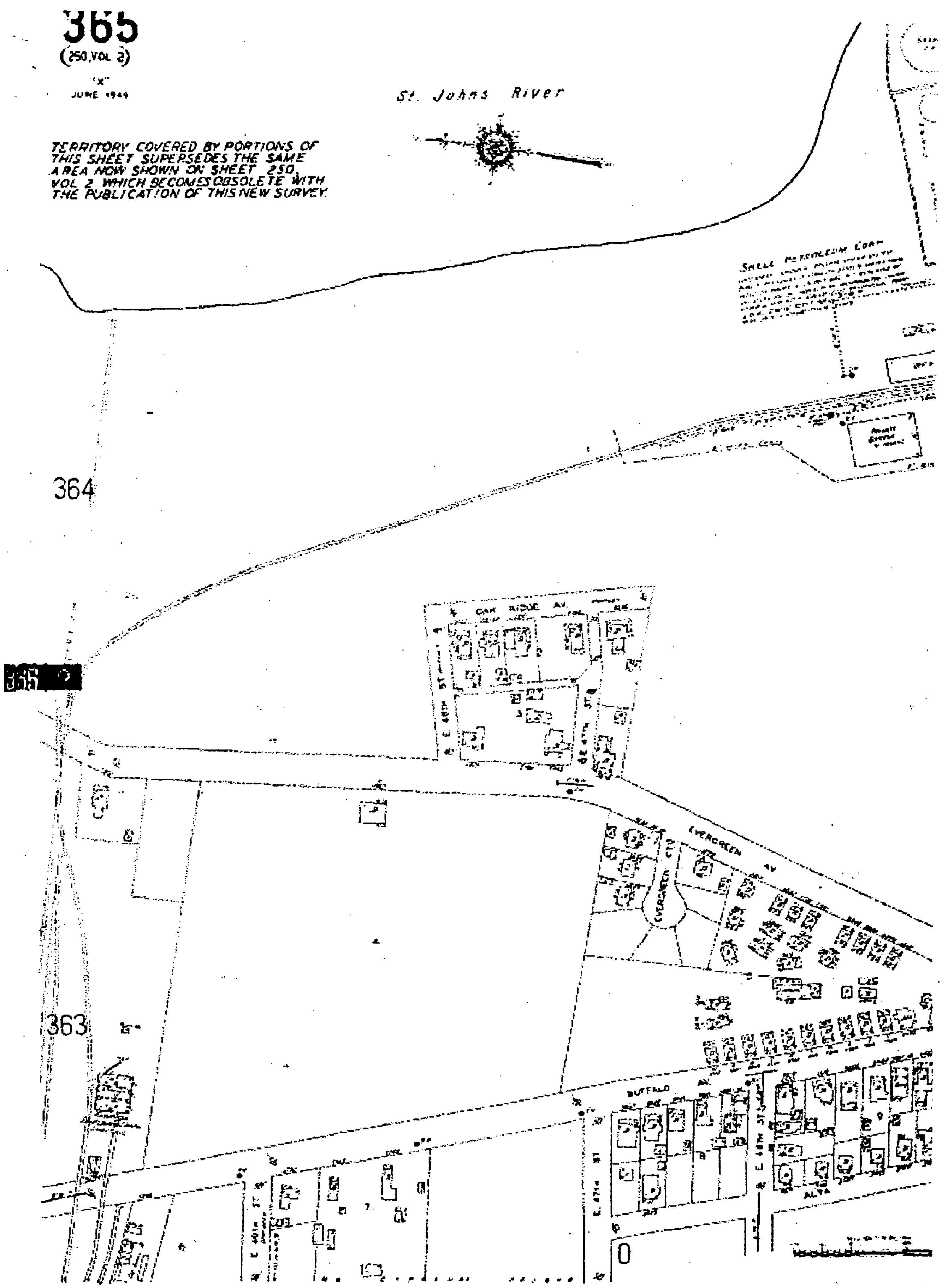
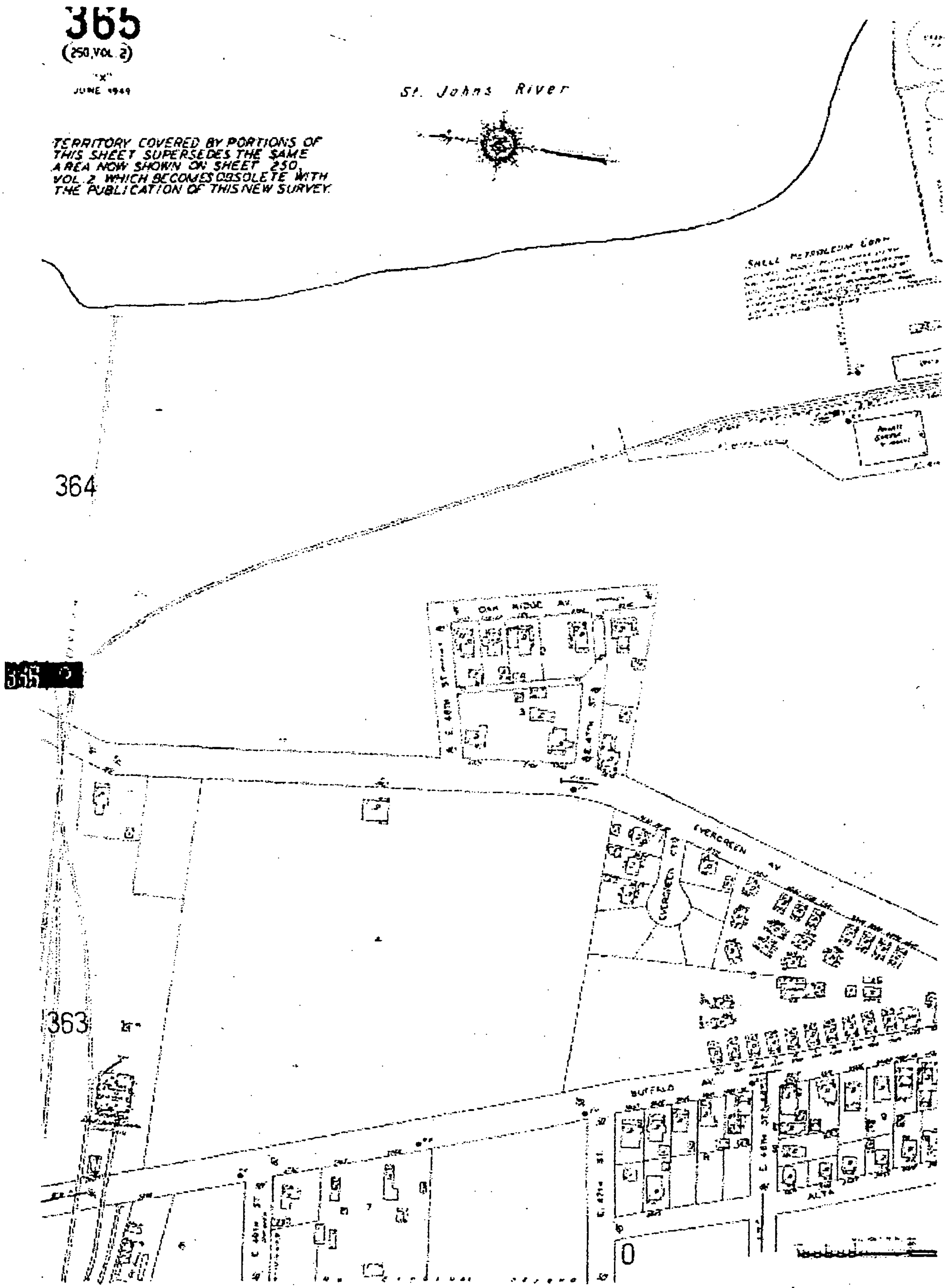
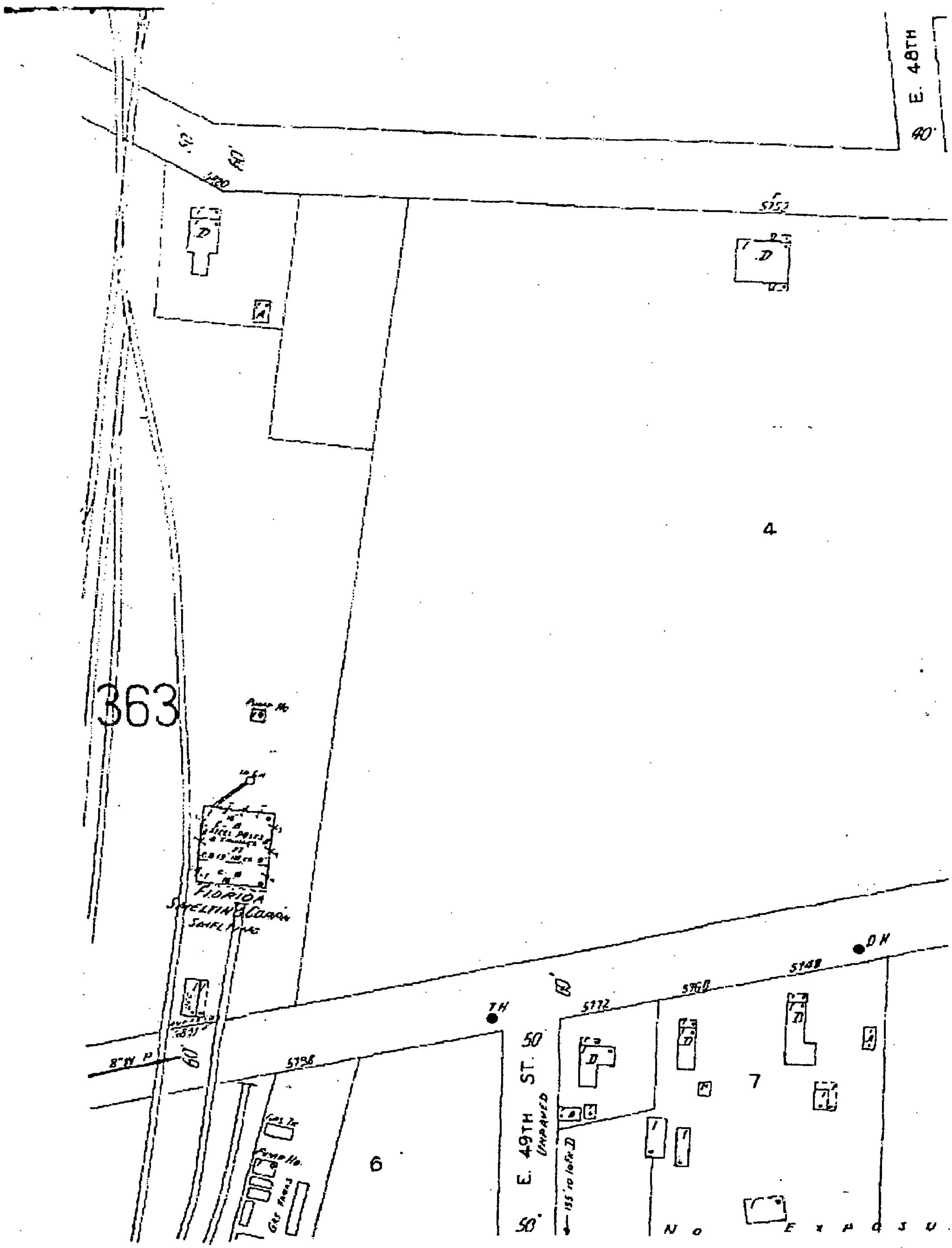
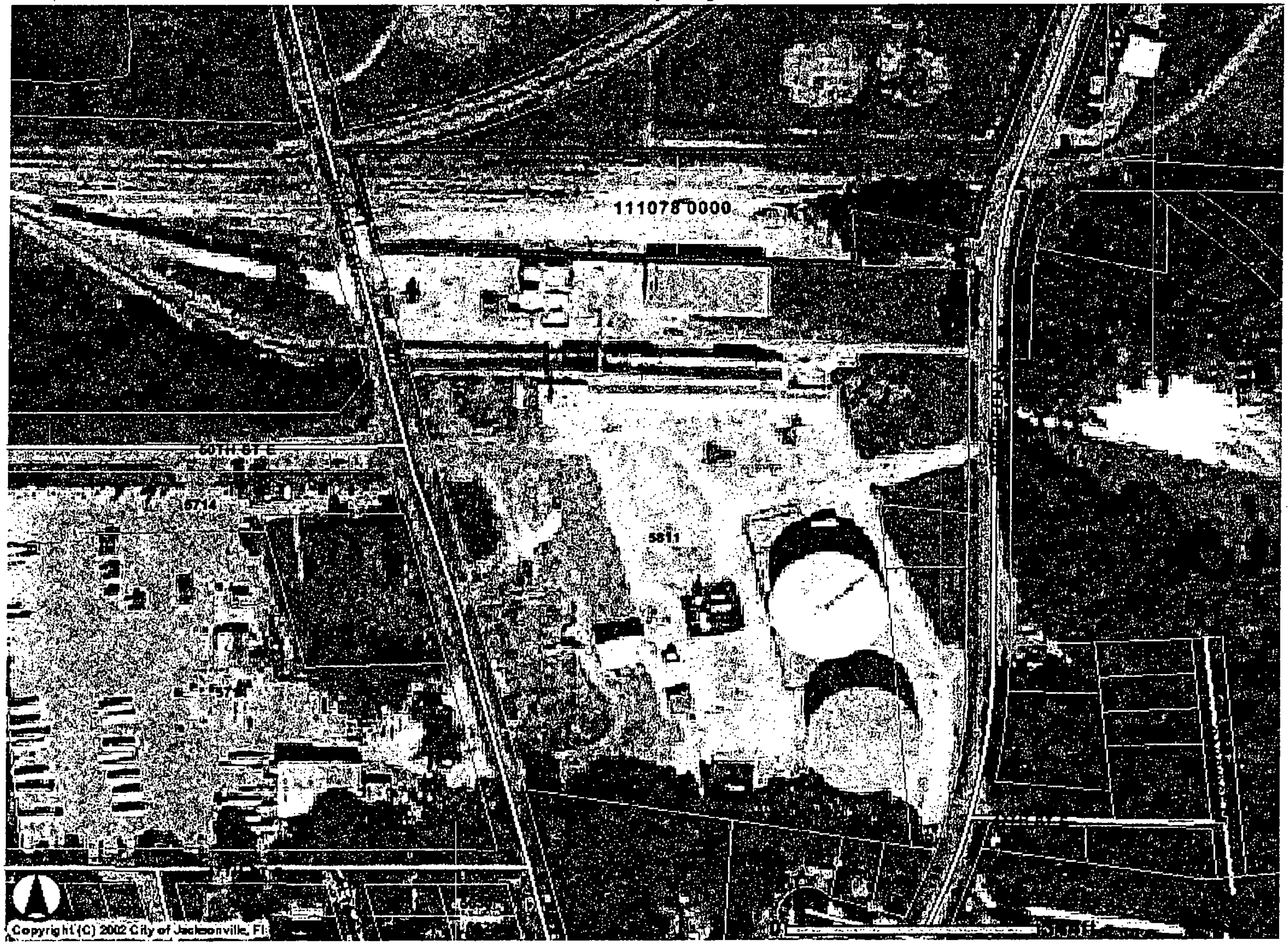

365
(250, VOL 2)
JUNE 1949
St. Johns River
TERRITORY COVERED BY PORTIONS OF THIS SHEET SUPERSEDES THE SAME AREA NOW SHOWN ON SHEET 250, VOL 2 WHICH BECOMES OBSOLETE WITH THE PUBLICATION OF THIS NEW SURVEY.
364
363
OAK RIDGE AV.
EVERGREEN AV
EVERGREEN CT
BUFFALO AV.
ALTA
0


365
(250, VOL. 2)
JUNE 1949
St. Johns River
TERRITORY COVERED BY PORTIONS OF THIS SHEET SUPERSEDES THE SAME AREA NOW SHOWN ON SHEET 250, VOL. 2 WHICH BECOMES OBSOLETE WITH THE PUBLICATION OF THIS NEW SURVEY.
364
OAK RIDGE AV.
EVERGREEN AV.
363
BUFFALO AV.
ALTA


E. 48TH
40'
4
363
FLORIDA
5772
5760
5748
5798
E. 49TH ST.
UNPAVED
50'
60'
6
7

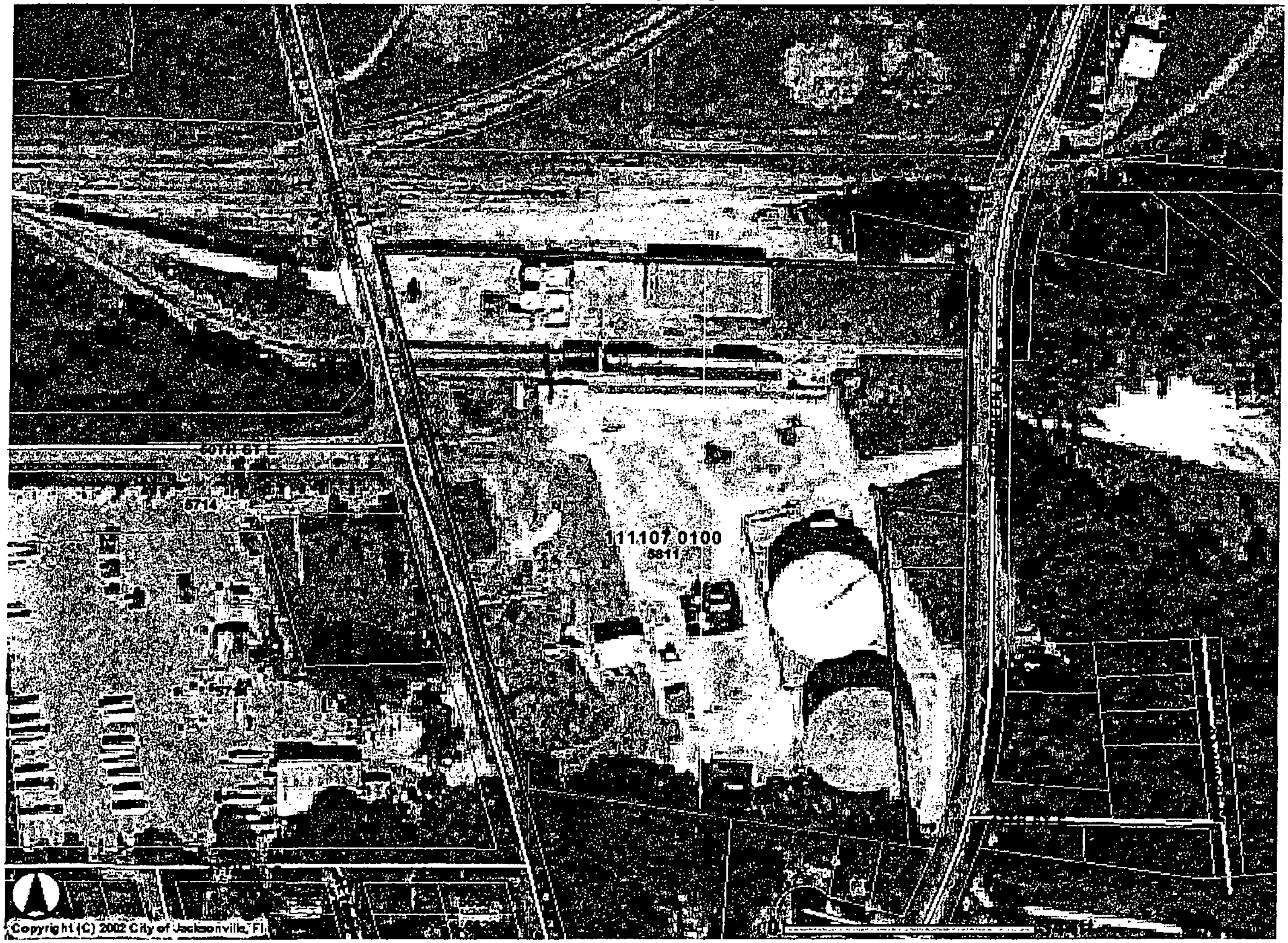
JAXGIS Property Information



RE #	Name	Address	Total Value	Acres	Plat Book	Map Panel	Legal Descriptions	Flood Zone	LandUse	Zoning	ENT
111078 0000	SEABOARD COASTLINE RR CO	32208	510632	15.63	0000	369 4	50-1S-27E 15.630 SIBBALD GRANT PT RECD D BK 118-405(EX O/R BKS	Not in Flood Zone	HI	IH	ENT

Reference 6

JAXGIS Property Information



RE #	Name	Address	Total Value	Acres	Plat Book	Map Panel	Legal Descriptions	Flood Zone	LandUse	Zoning	ENT
111107 0100	SUPPORT TERMINALS OPERATING PARTNSHP LP	5811 BUFFALO AV 32208	1051802	12.08	0004	369 4	2-83 50-1S-27E SAND FLY POINT PT BLK 4,	Not in Flood Zone	HI	IH	ENT

Property Appraiser

Parcel Information

Owner's Name: SEABOARD COASTLINE RR CO , **Secondary Name:**	**Real Estate Number:** 111078 0000

Property Address:
City: JACKSONVILLE
Zip: 32202
Unit Number:

Mailing Address: 500 WATER ST TAX DEPARTMENT
JACKSONVILLE , FL
Zip: 32202

PARCEL DESCRIPTION

Property Use: 9100 UTILITY	**Sale Date: 0/0/0**
Legal Description: 50-1S-27E 15.630 SIBBALD GRANT PT RECD D BK 118-405 (EX O/R BKS - 5496-1081,7373-2018), D BK 121-480(EX O/R BKS 5264-555, 5733-702),O/R BK 333-207	**Sale Price:** $0.00
Neighborhood: 000000 SECTION LAND COMM	
Section/Township/Range: 31-1S-27E	**No. Buildings:** 0
Official Record Book and Page:	**Heated Area:** 0
Map Panel: 369 4	**Exterior Wall:**

VALUES AND TAXES FROM 2003 CERTIFIED TAX ROLL

Land Value: $510,632.00	**Taxing Authority:** USD1
Class Value: $0.00	**County Tax:** $2,562.50
Improvements: $0.00	**School Tax:** $2,224.00
Market Value: $510,632.00	**District Tax:** $0.00

Assessed Value: $510,632.00	**Other Tax:** $130.34
Exempt Value: $250,210.00	**Voted Tax:** $133.08
Taxable Value: $260,422.00	
Sr. Exempt: $0.00	
Sr. Taxable: $0.00	**Total Tax:** $5,049.92

Printable Version

Additional Links:

Map This Property (MapIT) - Property Record Card (PRC) - Taxes - Back to Search Page

Map-It Feedback - Payment Feedback - Appraisal Feedback

All values from 2003 Certified Tax Roll. Updates weekly. Maps and data are not updated as frequently as the Tax Roll data and may not reflect matching information.

PARCEL INFORMATION

Owner's Name: SUPPORT TERMINALS OPERATING , PARTNSHP LP	**Real Estate Number:** 111107 0100

Property Address: 5811 BUFFALO AV
City: JACKSONVILLE
Zip: 32299
Unit Number:

Mailing Address: C/O RECOVERY & COMPLIANCE TAX
MESQUITE , TX
Zip:
75185-0186

PARCEL DESCRIPTION

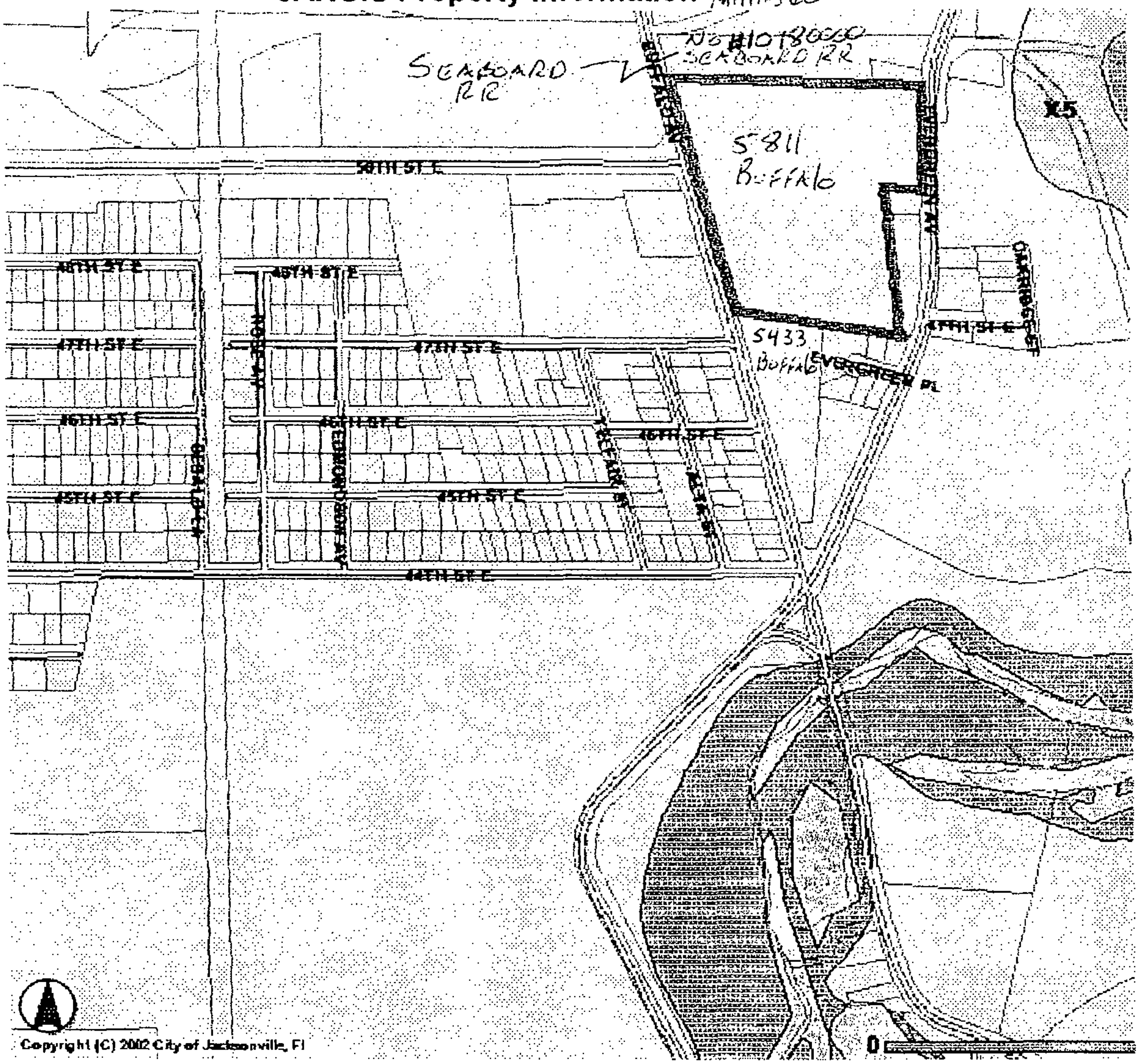
Property Use: 1700 OFFICE 1-2 STY	**Sale Date: 12/19/1995**
Legal Description: 2-83 50-1S-27E SAND FLY POINT PT BLK 4, - PT SIBBALD GRANT SEC 50-1S-27E RECD O/R 8245-96 BEING PARCEL 2	**Sale Price:** $32,331,300.00
Neighborhood: 001939 SAND FLY POINT S/D COMM	
Section/Township/Range: 31-1S-27E	**No. Buildings:** 3
Official Record Book and Page: 08245-0096	**Heated Area:** 12940
Map Panel: 369 4	**Exterior Wall:** CB STUCCO

VALUES AND TAXES FROM 2003 CERTIFIED TAX ROLL

Land Value: $789,269.00	**Taxing Authority:** USD1
Class Value: $0.00	**County Tax:** $10,349.52
Improvements: $262,533.00	**School Tax:** $8,982.39
Market Value: $1,051,802.00	**District Tax:** $0.00
Assessed Value: $1,051,802.00	**Other Tax:** $526.42
Exempt Value: $0.00	**Voted Tax:** $537.47
Taxable Value: $1,051,802.00	
Sr. Exempt: $0.00	
Sr. Taxable: $0.00	**Total Tax:** $20,395.80

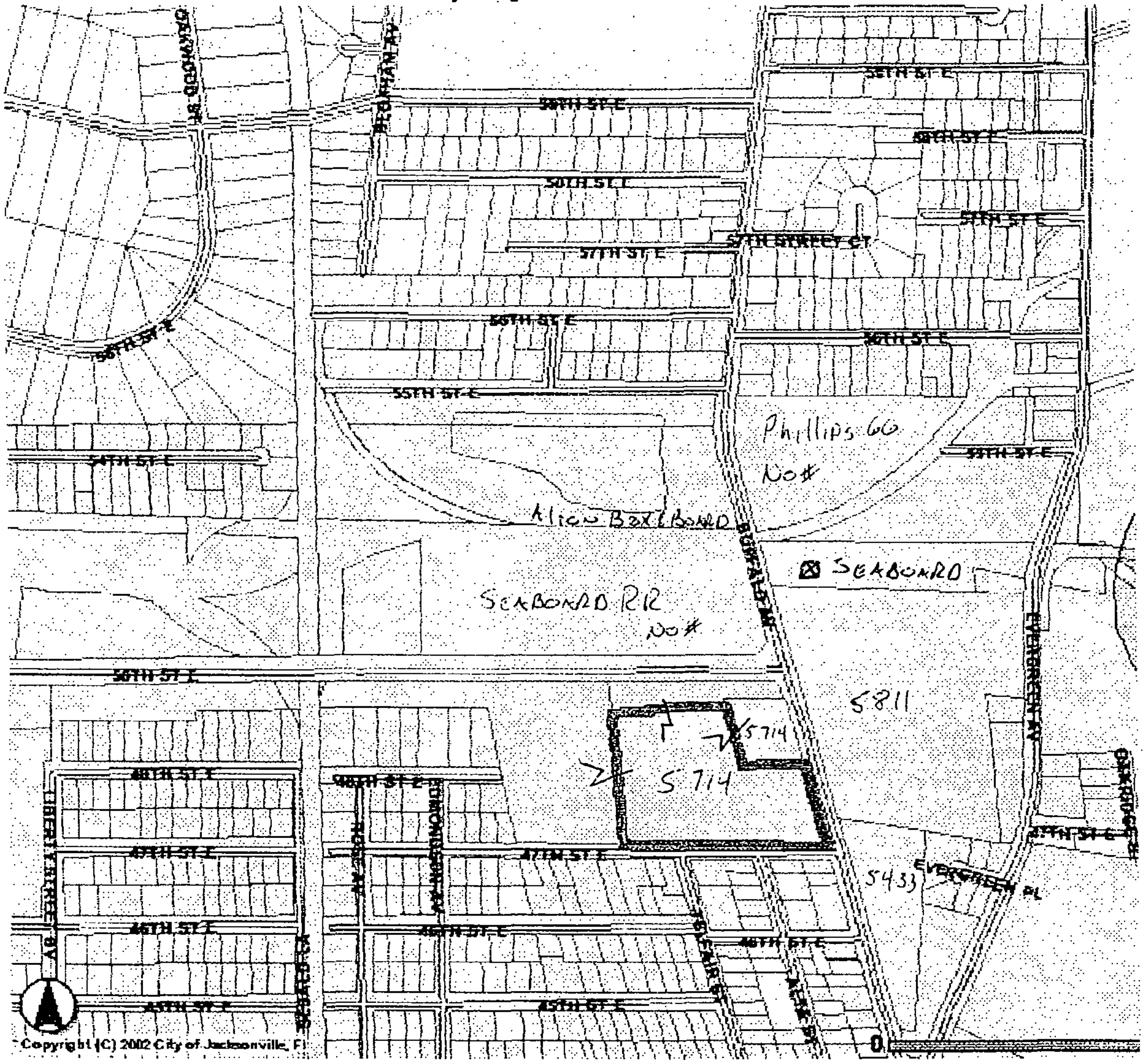
JAXGIS Property Information

No #



RE #	Name	Address	Total Value	Acres	Plat Book	Map Panel	Legal Descriptions	Flood Zone	LandUse	Zoning
111107 0100	SUPPORT TERMINALS OPERATING PARTNSHP LP	5811 BUFFALO AV 32208	1055414	12.08	0004	369 4	2-83 50-1S-27E SAND FLY POINT PT BLK 4,	NO	HI	IH

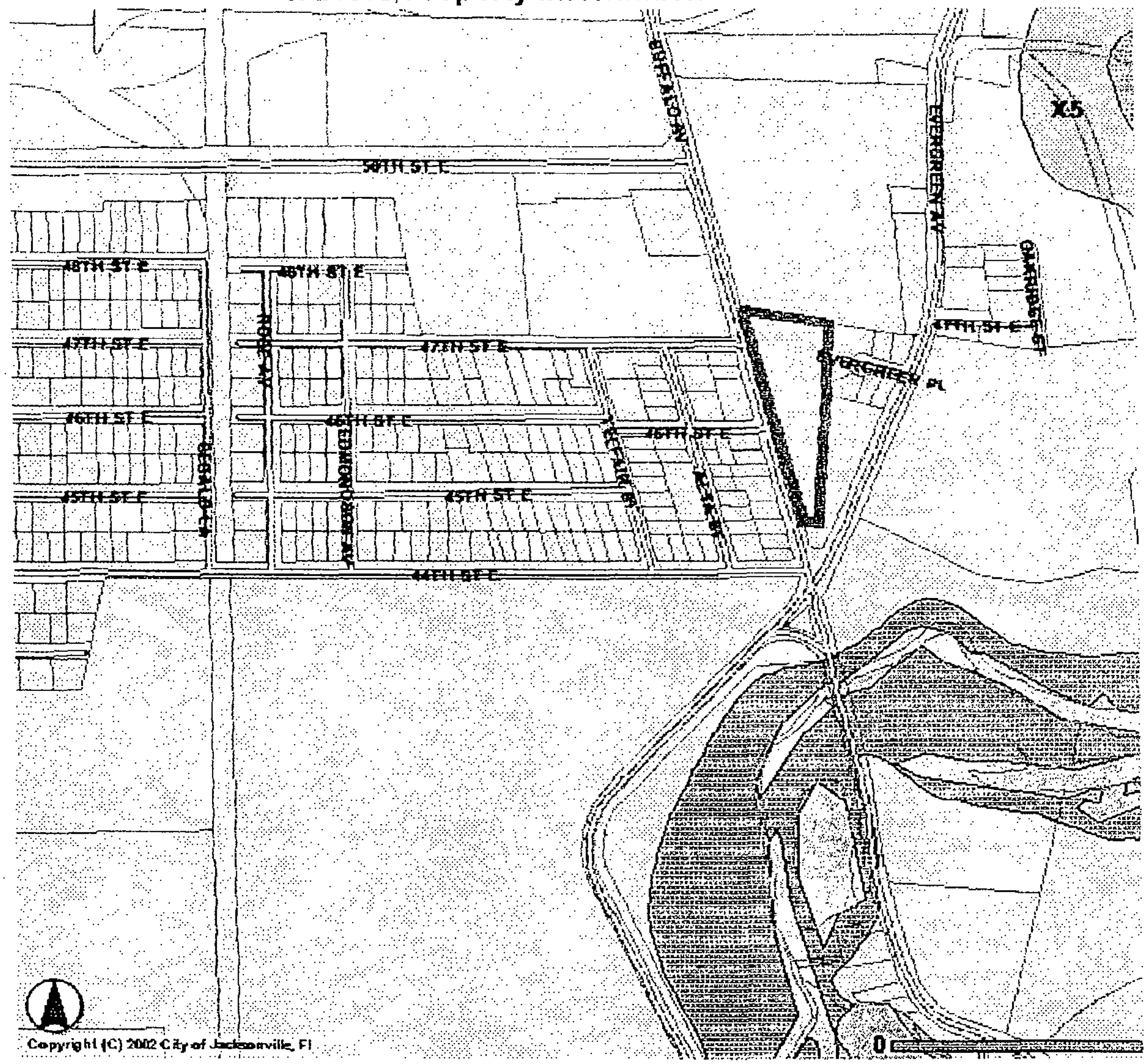
JAXGIS Property Information



RE #	Name	Address	Total Value	Acres	Plat Book	Map Panel	Legal Descriptions	Flood Zone	LandUse	Zo
111124 0000	FLORIDA ROCK & TANK LINES, INC	5714 BUFFALO AV 32208	321362	5.68	0000	369 3	7-6 50-1S-27E STOCKTONS S/D PT TRACT 2 RECD O/R BK 2402-691	NO	LI	IL

☒ Approx. Site Location

JAXGIS Property Information



RE #	Name	Address	Total Value	Acres	Plat Book	Map Panel	Legal Descriptions	Flood Zone	LandUse	Zoning
111083 0000	HITZING REALTY CORP	5433 BUFFALO AV 32208	610207	2.23	0000	369 4	50-1S-27E SIBBALD GRANT PT RECD O/R BK 1015-121	NO	WD/WR	IW

JACKSONVILLE WSO AP, FLORIDA

Period of Record General Climate Summary - Temperature

Station:(084358) JACKSONVILLE WSO AP

From Year=1948 To Year=2003

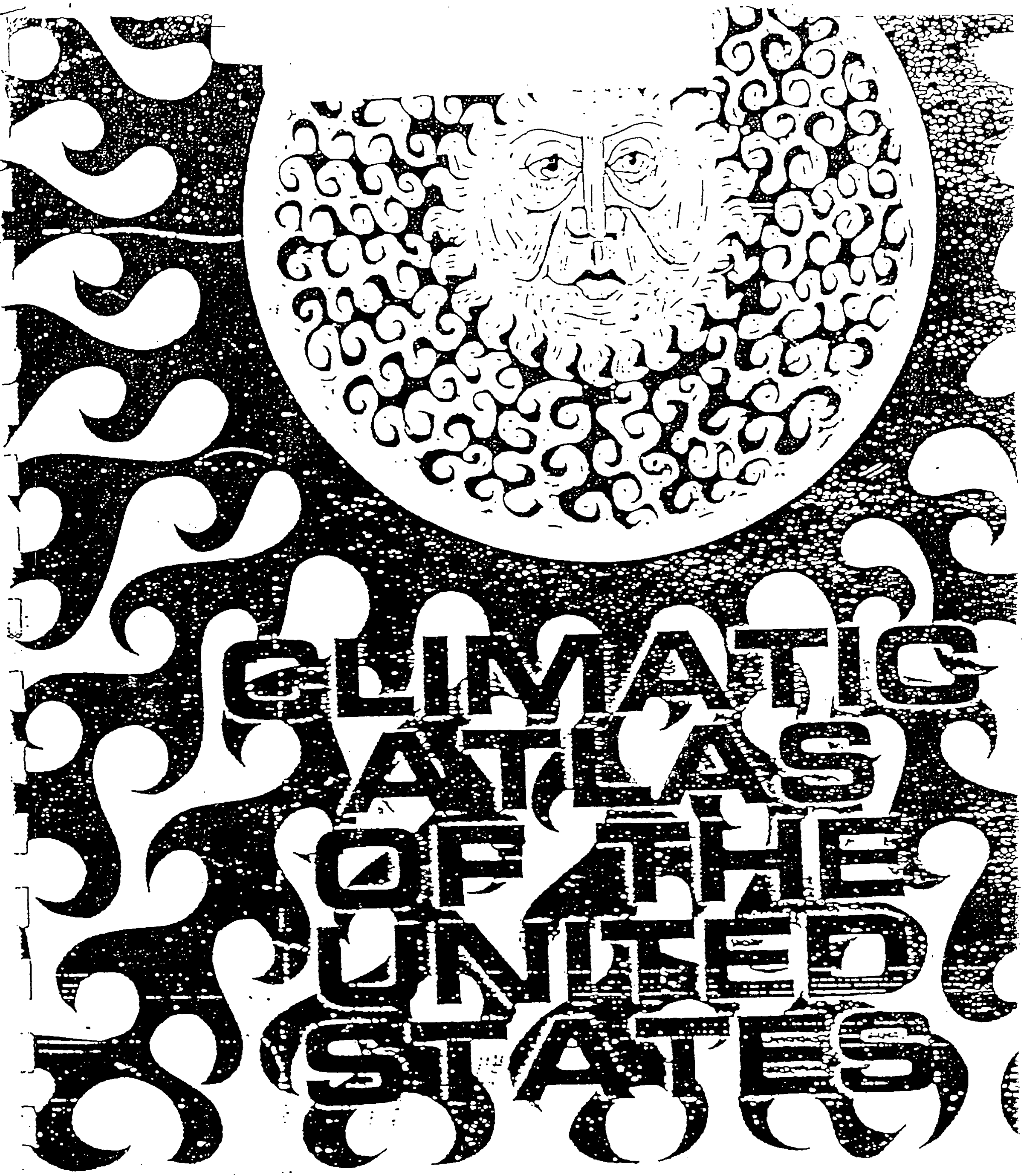
	Monthly Averages			Daily Extremes				Monthly Extremes				Max. Temp.		Min. Temp.	
	Max.	Min.	Mean	High	Date	Low	Date	Highest Mean	Year	Lowest Mean	Year	>= 90 F	<= 32 F	<= 32 F	<= 0 F
	F	F	F	F	dd/yyyy or yyyymmdd	F	dd/yyyy or yyyymmdd	F	-	F	-	# Days	# Days	# Days	# Days
January	65.0	42.6	53.8	84	29/1957	7	21/1985	66.7	74	44.0	***	0.0	0.0	6.2	0.0
February	67.9	45.2	56.6	88	24/1962	19	05/1996	65.2	49	47.5	***	0.0	0.0	3.4	0.0
March	73.7	50.4	62.0	91	12/1967	23	03/1980	67.9	61	55.4	***	0.1	0.0	0.8	0.0
April	79.8	56.3	68.0	95	21/1968	34	01/1987	73.0	68	62.6	83	1.4	0.0	0.0	0.0
May	85.9	63.7	74.8	100	13/1967	45	04/1971	80.6	53	71.4	76	8.1	0.0	0.0	0.0
June	89.8	70.1	80.0	103	27/1950	47	01/1984	84.5	52	75.8	66	16.2	0.0	0.0	0.0
July	92.0	72.8	82.4	103	17/1981	61	08/1972	84.4	81	78.9	74	23.7	0.0	0.0	0.0
August	90.9	72.6	81.7	102	05/1954	59	12/2000	84.9	54	79.1	96	20.7	0.0	0.0	0.0
September	87.1	70.1	78.6	98	02/1970	48	19/1981	81.3	70	75.3	101	9.9	0.0	0.0	0.0
October	80.2	60.7	70.4	96	06/1951	36	18/1977	76.4	49	63.9	87	1.2	0.0	0.0	0.0
November	72.9	50.8	61.9	88	01/1961	21	25/1970	69.9	48	54.2	76	0.0	0.0	0.9	0.0
December	66.4	44.2	55.3	84	23/1956	11	25/1983	64.3	71	47.7	89	0.0	0.0	4.4	0.0
Annual	79.3	58.3	68.8	103	19500627	7	19850121	71.4	49	66.2	76	81.3	0.0	15.7	0.0
Winter	66.5	44.0	55.2	88	19620224	7	19850121	62.3	50	48.9	77	0.0	0.0	14.0	0.0

Reference 7

Spring	79.8	56.8	68.3	100	19670513	23	19800303	72.1	91	64.3	83	9.6	0.0	0.8	0.0
Summer	90.9	71.9	81.4	103	19500627	47	19840601	83.6	54	78.7	74	60.6	0.0	0.0	0.0
Fall	80.1	60.5	70.3	98	19700902	21	19701125	74.2	85	65.2	76	11.1	0.0	0.9	0.0

Table updated on Oct 14,
For monthly and annual means, thresholds, and sums:
Months with 5 or more missing days are not considered
Years with 1 or more missing months are not considered
Seasons are climatological not calendar seasons
Winter = Dec., Jan., and Feb. Spring = Mar., Apr., and May
Summer = Jun., Jul., and Aug. Fall = Sep., Oct., and Nov.

Southeast Regional Climate Center, sercc@dnr.state.sc.us



onmental Science Services Administration • Environment

U.S. DEPARTMENT OF COMMERCE
C. R. Smith, Secretary

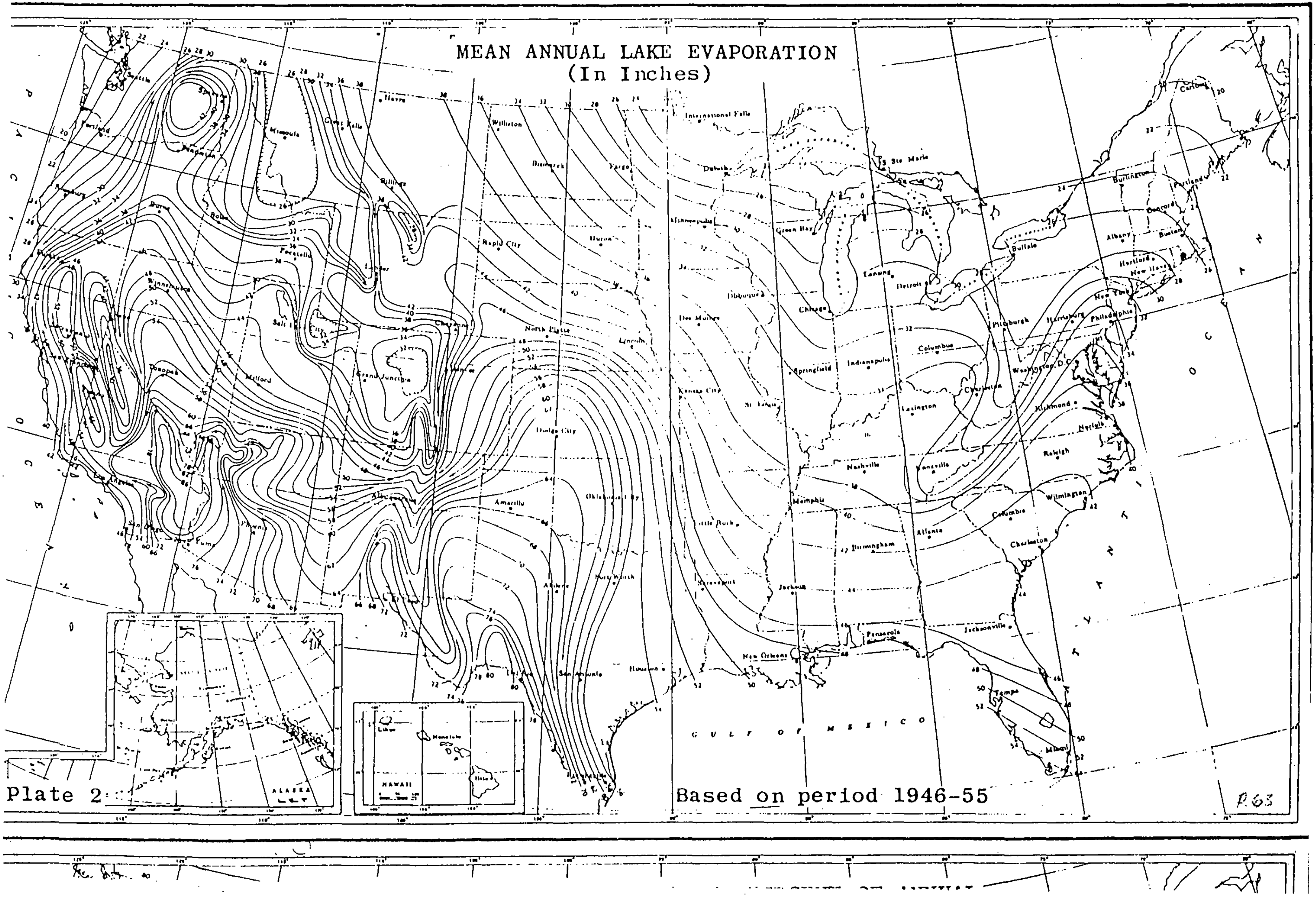
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Robert M. White, Administrator

ENVIRONMENTAL DATA SERVICE
Woodrow C. Jacobs, Director

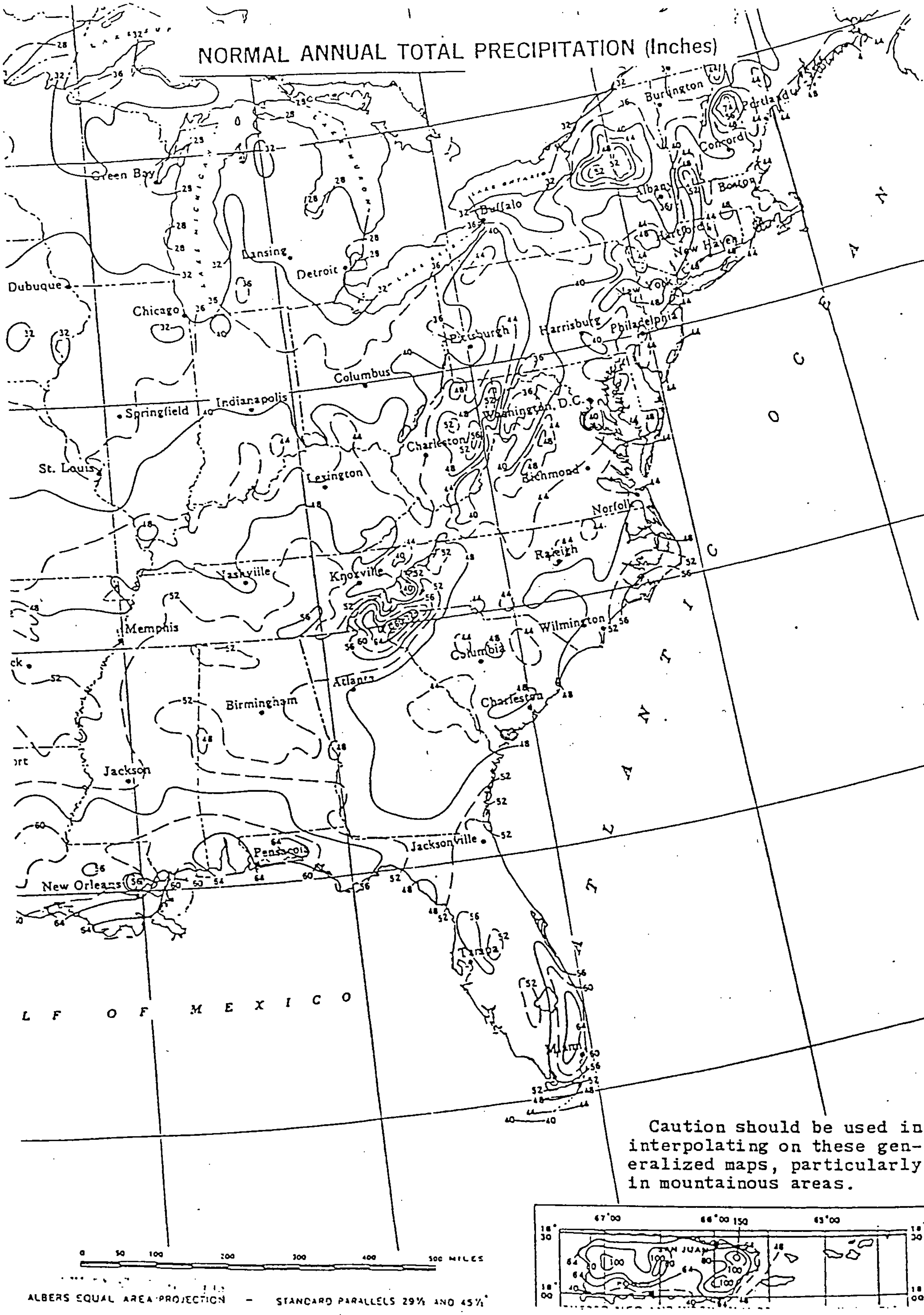
JUNE 1968

REPRINTED BY THE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
1983

ıKE EVAPORATION



NORMAL ANNUAL TOTAL PRECIPITATION (Inches)



Caution should be used in interpolating on these generalized maps, particularly in mountainous areas.

PREVAILING DIRECTION AND MEAN SPEED (M.P.H.) OF WIND
ANNUAL

NOTE:
Arrows fly with wind.

)MMERCE

WEATHER
F.W. Reich...

TECHNICAL PAPER NO. 40

RAINFALL FREQUENCY ATLAS OF THE UNITED STATES

for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years

Prepared by
DAVID M. HERSHFIELD
Cooperative Studies Section, Hydrologic Services Division

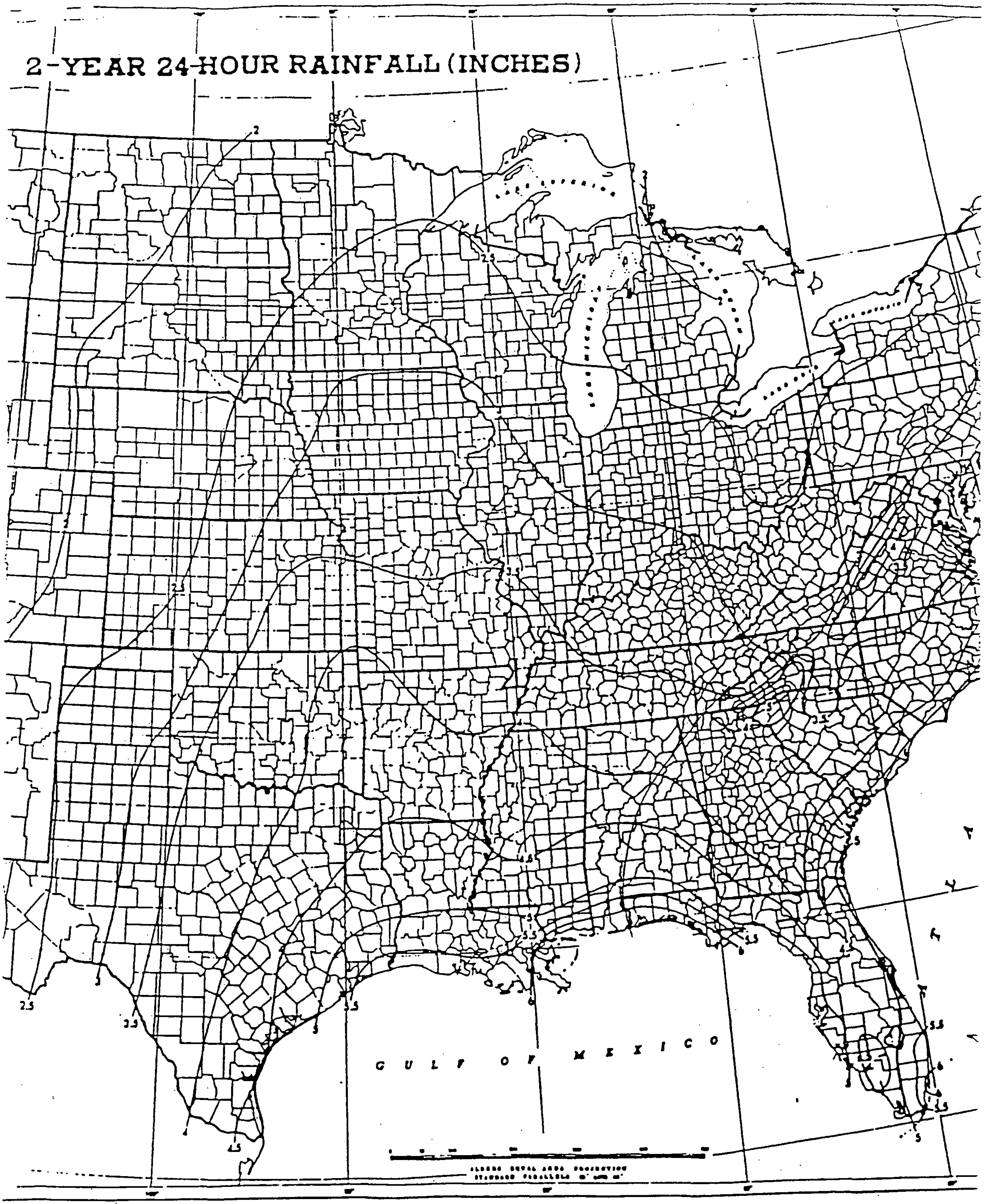
for

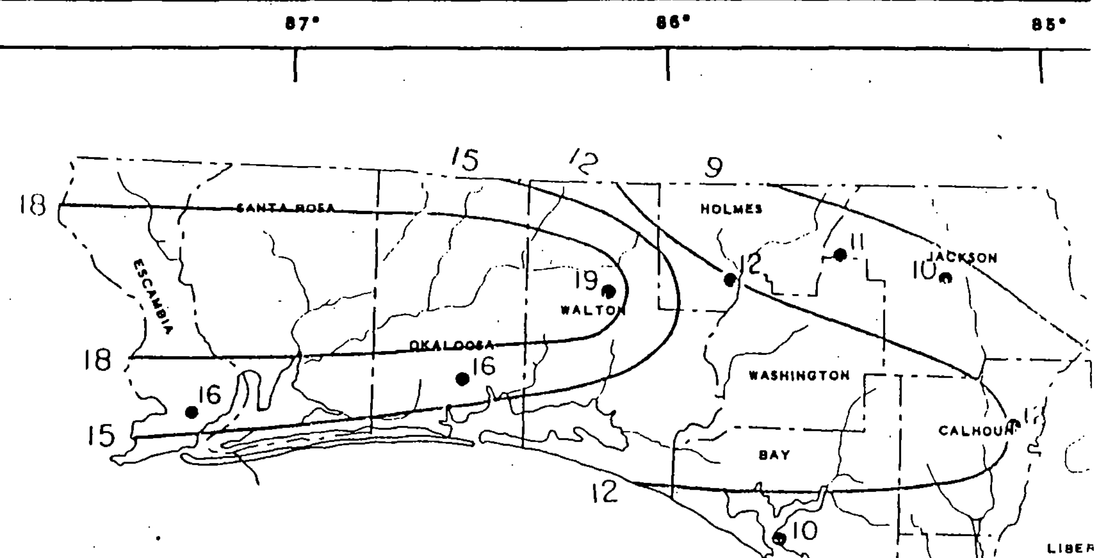
Engineering Division, Soil Conservation Service
U.S. Department of Agriculture

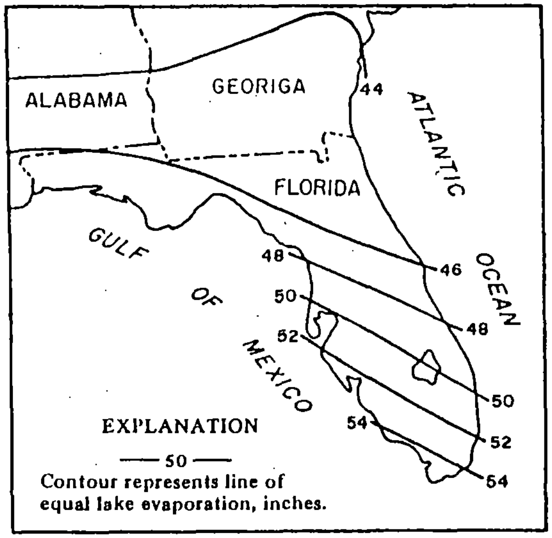
Ref 5

Reference 9

2-YEAR 24-HOUR RAINFALL (INCHES)







AVERAGE ANNUAL LAKE EVAPORATION

THE DIFFERENCE BETWEEN RAINFALL AND POTENTIAL EVAPORATION IN FLORIDA

By

F. N. Visher and G. H. Hughes

Prepared by
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES
TALLAHASSEE, FLORIDA

1969
SECOND EDITION 1975

Rainfall in Florida is generally abundant, but man presently has little opportunity to control or direct the use of a large part of the total rainfall. Evaporation from land, water and plant surfaces has first call on much of the rainfall. Evaluation of the amount and areal variation of rainfall in excess of all evaporative losses is a necessary factor in appraising the outflow of water from an area. Outflow is the total surface and ground water flow from an area, and is equal to the difference between rainfall on an area and actual evaporation from an area.

Present technology does not permit accurate determination of evaporation from large areas of diversified soils and vegetative cover where the availability of water may differ and vary both in time and in space. Thus, outflow is not determined directly, but is evaluated by determining the incremental outflow that results from the excess rainfall in the area. Such an approach usually is practicable in areas where the total outflow occurs in well-defined surface channels. In Florida, however, many areas are underlain by permeable limestone aquifers which transcend surficial drainage divides and which transmit large quantities of water underground. Even though part of the water

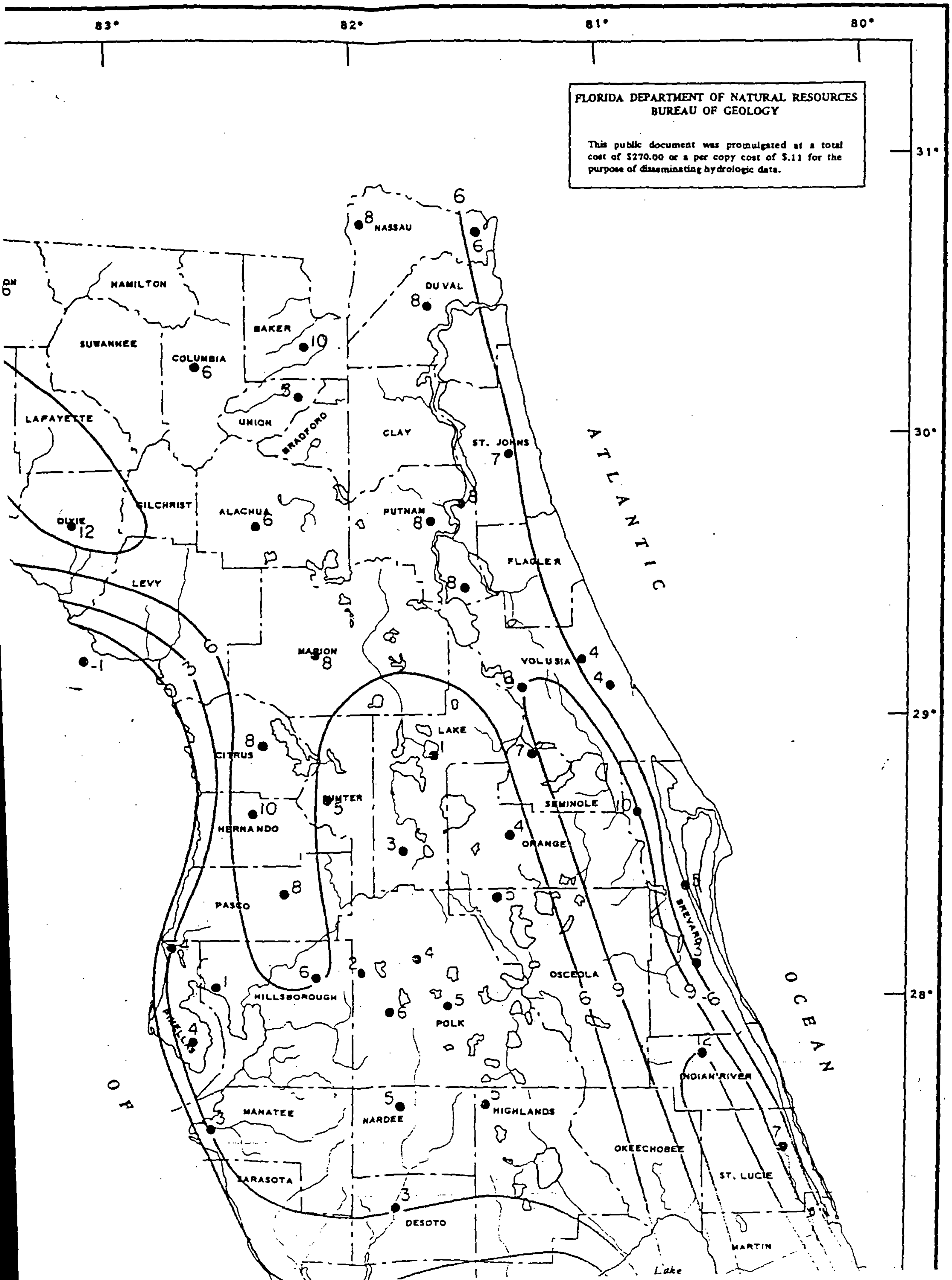
The values shown by the evaporation map depend on meteorological factors such as solar radiation, wind movement, air temperature, and humidity, all of which are importantly related to lake evaporation. Thus, the values are applicable to individual lakes as long as the lakes are openly exposed to wind movement, a requirement met by most large lakes in Florida. The same requirement may not be met by some small lakes covering only a few acres that may lie at the bottom of deep sinkhole depressions or that may be entirely rimmed by tall and dense vegetation.

Yearly potential evaporation varies only slightly compared to yearly rainfall, which in many areas of Florida ranges from about 50 percent greater than normal to about 50 percent less than normal. Although some of the excess rainfall of wet years may be carried over as soil moisture or stored in lakes or in a shallow water table, much of the excess rainfall flows out of the area and does not remain available for evaporation in subsequent years. Similarly, but in a somewhat opposite sense, the energy represented by potential evaporation that cannot be used because of a lack of water during a dry year is not stored for later use but rather is dissipated. Because the yearly and seasonal

In northeast Florida, the di
evaporation ranges from 6 t
panhandle area. In the part
entirely or almost entirely in
about 14 inches. Large areas
evaporation losses are almost
other hand, larger areas are n
of surface streams. Much of th
downward to the water table a
without large evaporation losse

Over a large part of central
and potential evaporation is 1
part of this area, including prin
of Polk County, there are num
of this area, evaporation a
evaporation potential and ru
difference between the rainf
runoff from the area, as mea
Withlacoochee River, the Little

FLORIDA DEPARTMENT OF NATURAL RESOURCES
published by BUREAU OF GEOLOGY



Lead > Secondary Lead Smelter eTool

eTool Hom

Raw Mate
Processin

Smelting

Blast Furn

Reverber
Furnace

Refining
Casting

Environm
Controls

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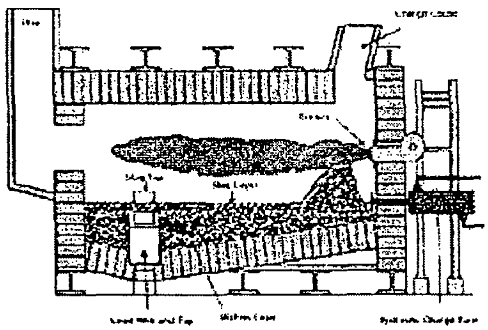
Engineeri
Controls

OSHA Lea
Requirem

Smelting > Reverberatory Furnace

Reverberatory furnaces are designed and operated to produce a soft, nearly pure lead product. Reverberatory furnaces emit high levels of lead fume during the following processes:

- Charging
- Tapping Lead and Slag



Click for larger view of reverberatory furnace

Charging

Potential Sources of Exposure:

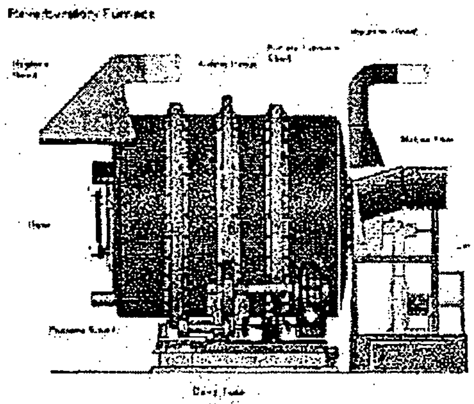
- Spillage or emissions may occur at feed conveyor transfer and charging points of the reverberatory furnace.
- Emissions may occur through leaks in refractory material, which allow lead dust and fumes to escape.
- Lead fume and dust may be emitted from the reverberatory furnace if the furnace is run at positive pressure or if bridging occurs during charging wet materials.

Reverberatory furnace tap hole hood

Possible Engineering and Work Practice Controls:

- Enclose and provide exhaust ventilation for the reverberatory furnace.
- Provide hooding with sufficient exhaust ventilation to capture dust that may be generated by filling or emptying charge material conveyors.
  ▶ Conveyor Belt Ventilation Diagram

- Maintain positive-pressure, HEPA filtered air system on mobile equipment to ensure effective operation. Check and change air filters regularly as part of an effective scheduled preventative maintenance program.
  ▶ Tempered Air Cab Diagram



Click for larger view of reverberatory furnace diagram

- Maintain raw material storage and handling areas under negative pressure to prevent contamination of adjacent furnace areas.
- Provide process controls to maintain sufficient negative air pressure on the furnace during charging to prevent puffing.
- Do not overfill conveyors and ram feeders.
- Vacuum any spills immediately with a HEPA filtered vacuum system. Water should not be used for dust suppression in the smelting area due to the possibility of oxide fires and the mixing of water and molten lead.

Tapping

Reverberatory furnace tapping operations involve pouring the molten lead and slag from the furnace into molds or ladles. Some smelters tap metal directly into a holding kettle, which keeps the metal molten for refining. Other smelters cast the furnace metal into blocks and allow the blocks to solidify.

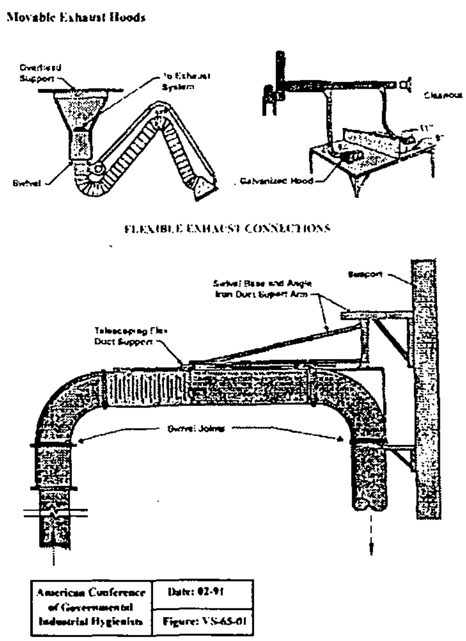
Reverberatory furnace lead tap with local exhaust ventilation

Potential Sources of Exposure:

- Lead fumes may be emitted at the lead or slag tapping plugs during removal of the tapping plug or while lancing the tapping plug.
- Pouring lead or slag into the tapping launder, mold, ladle or refining kettle may emit fumes.
- Lead dust may become airborne due to the disturbance of settled dust in the smelting area.
- Ladles containing slag or molten lead may emit fumes.
- Spilled slag or molten lead may emit lead fumes.

Possible Engineering and Work Practice Controls:

- Provide local exhaust ventilation at the lead and slag tap, launders, molds, ladles, and refining kettles.
- Allow lead and slag pots to remain under the exhaust hood until crusted to minimize the emission of fume.
  ▶ Secondary Exhaust Hood Diagram
- Provide supplied air island at lead and slag tapping stations.
  ▶ Supplied Air Island Diagram
- Provide local exhaust ventilation for staged slag pots if necessary.
  ▶ Moveable Exhaust Hood Diagram
- Reline or repair refractory as necessary to minimize lead fume leakage from furnace.



Click for larger view of moveable exhaust hood diagram

Occupational Safety & Health Administration
200 Constitution Avenue, NW
Washington, DC 20210

Lead > Secondary Lead Smelter eTool

eTool Hom

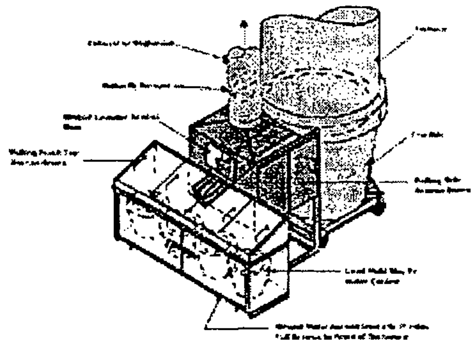
Raw Mate Processin
Smelting
Blast Furı
Reverberat Furnace
Refining ᵼ Casting
Environm Controls
Maintenaı
Engineeri Controls
OSHA Lea Requirem

Smelting > Blast Furnace

Blast furnaces are designed and operated to produce a hard (high alloy content) lead product. Blast furnaces emit high levels of lead fume dúring the the following processes:

- Charging
- Tapping
- Tuyere Punching

▶ Cross-sectional view of blast furnace
▶ Additional blast furnace images

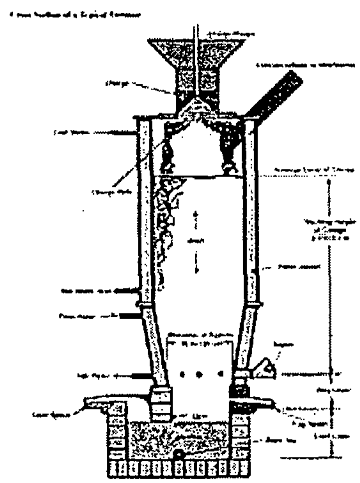


Click for larger view of blast furnace lead tap controls diagram

Charging

Potential Sources of Exposure:

- Spillage or emissions may occur at blast furnace feed conveyor transfer points and charging points.
- Spillage of lead-containing dust may occur if bucket elevators, conveyors, or skip hoists are overfilled.
- Lead fume and dust may be emitted from the blast furnace if the charge level is too low.



Click for larger view of blast furnace diagram

Possible Engineering and Work Practice Controls:

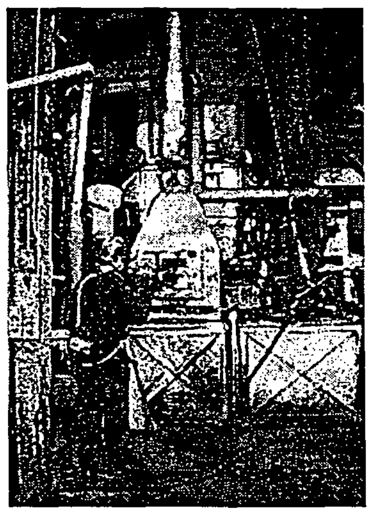
- Maintain raw material storage and handling areas under negative pressure to prevent contamination of adjacent work areas.
- Prevent puffing by providing and maintaining process controls to ensure that the proper amount of charge material is in the thimble on the top of the

furnace.

- Provide hooding with sufficient exhaust ventilation at furnace feed conveyor loading and charge points to capture dusts and fumes which may be emitted.
- Provide hooding with sufficient exhaust ventilation to capture dusts which may be generated when charging the furnace.
- Do not overfill bucket elevators, conveyors, or skip hoists.
- Maintain positive-pressure, HEPA filtered air systems on mobile equipment to ensure effective operation. Check and change air filters regularly as part of an effective scheduled preventative maintenance program.
- Vacuum any spills immediately with a HEPA filtered vacuum system. Water should not be used in the smelting area for dust suppression due to the possibility of oxide fires and the mixing of water and molten lead.

Tapping

Blast furnace tapping operations involve removing the slag and then tapping molten lead from the furnace into molds or ladles. Some smelters tap metal directly into a holding kettle which keeps the metal molten for refining. The other smelters cast the furnace metal into blocks and allow the blocks to solidify.



Slag tap with enclosure hooding and local exhaust ventilation

Potential Sources of Exposure:

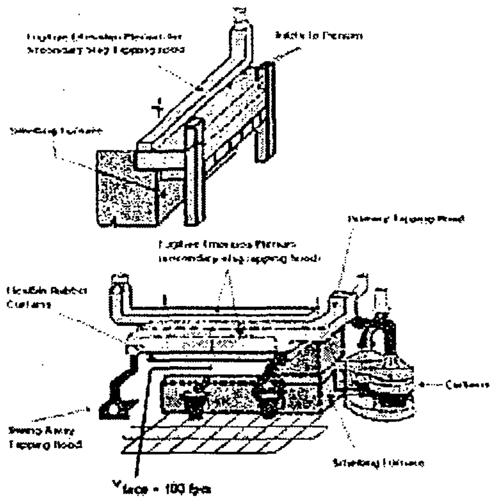
- Lead fumes may be emitted at the lead or slag tapping plugs during removal of the tapping plug or while lancing the tapping plug.
- Emissions may occur while pouring lead or slag at the tapping launder, mold, ladle, or refining kettle.
- Lead dust may become airborne due to disturbance of settled dust in the smelting area.
- Emissions may occur from ladles containing slag or molten lead.
- Spilled slag or molten lead may emit lead fumes.

Possible Engineering and Work Practice Controls:

- Provide local exhaust ventilation at the lead and slag tap, launders, molds,

ladles, and refining kettles.
▶ Blast Furnace Lead Tap Controls Diagram
▶ Blast Furnace Slag Tap Controls Diagram

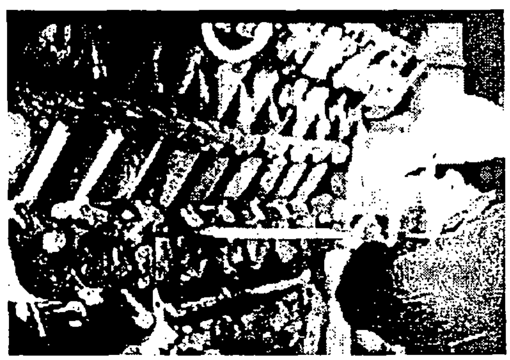
- Allow lead and slag pots to remain under the exhaust hood until crusted to minimize fume emissions.
  ▶ Secondary Exhaust Hood Diagram
- Provide a supplied air island at lead and slag tapping stations.
  ▶ Supplied Air Island Diagram
- Provide local exhaust ventilation for staged slag pots if necessary.
  ▶ Moveable Exhaust Hood Diagram



Click for larger view of secondary exhaust hood diagram

Tuyere Punching

Blast air for the combustion process enters the blast furnace through "tuyeres." The tuyeres occasionally begin to fill with accretions and must be physically punched, usually with a steel rod, to keep them unobstructed. The conventional method used for this task is to remove the cover of the tuyeres and insert the steel rod. After the accretions have been "punched," the cover is replaced.



Manual tuyere punching

Recently smelters have been able to adapt an "off-the-shelf" automatic tuyere puncher that has greatly reduced employee lead exposure. However, even with the automatic system there are occasions when the tuyere pipe has to be cleared by using a jackhammer or rod.

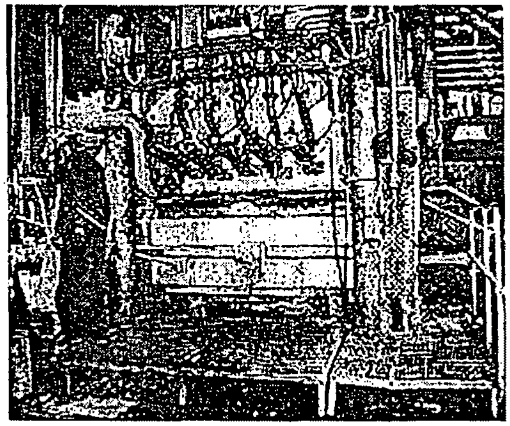
Potential Sources of Exposure:

- Significant lead fume emissions may come from the furnace during manual punching.

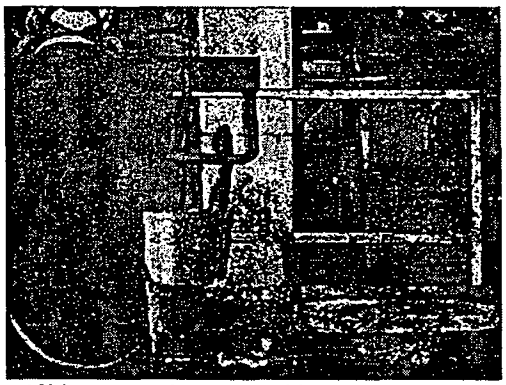
Possible Engineering and Work Practice Controls:

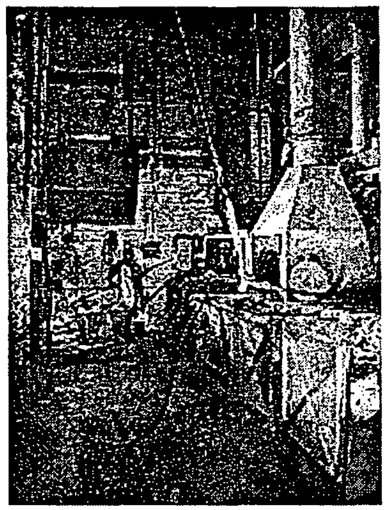
- Provide automatic tuyere punching.
  ▶ Hydraulic Tuyere Punch Diagram
- Use notched, rotating tuyere covers to minimize tuyere opening during punching.

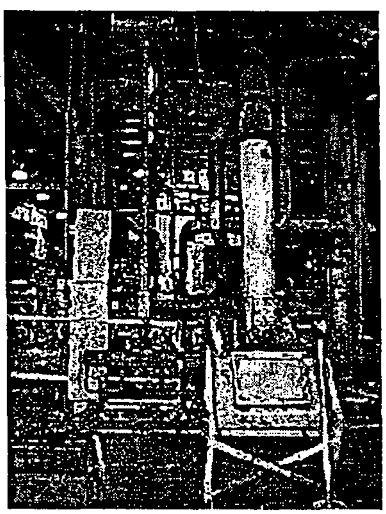
- Stand to the side of the tuyere when opening the cover during the tuyere punching operation.
- Provide a rod of sufficient length to minimize operator exposure.
- Provide a viewing port on the tuyere cover so that plugging can be observed without removing the cover.

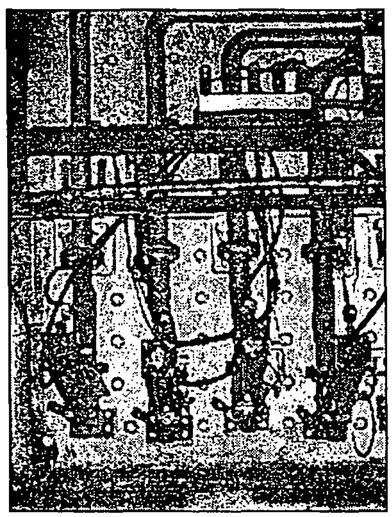

Automatic tuyere puncher

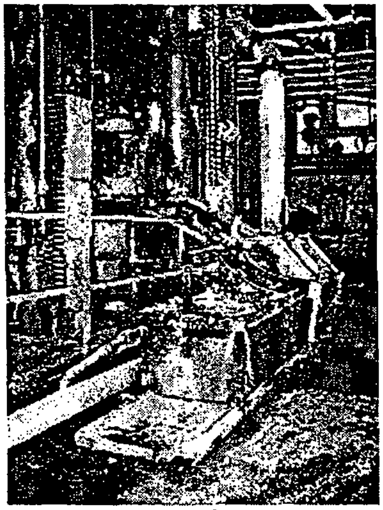
Additional Images


Lifting recently cast lead blocks from mold


Slag side of blast furnace


Local exhaust ventilation at lead tap


Automatic tuyere punch


Liquid lead cooling in molds


Lead flowing into mold

eTool Home	Raw Materials Processing	Smelting	Refining and Casting
Environmental Controls	Maintenance	Engineering Controls	OSHA Lead Requirements
Scope	Definitions	Additional References	User Guide	Credits

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Occupational Safety & Health Administration
200 Constitution Avenue, NW
Washington, DC 20210

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

LEVEL

All-Weather Notebook
No. 311

Fla. Smelting Co.- Buffalo (FSC Buffalo)
Jacksonville, Duval Co., Florida
EPA ID FLN000407555
Logbook #1

4 5/8" x 7" - 48 Numbered Pages

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

INCHES

Name ______________________________

Address ______________________________

Phone ______________________________

Project ______________________________

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CONTENTS

PAGE	REFERENCE	DATE

April 11, 2003

Travel To Jax, Fla. To View Several Sites That TN & Assoc. (TN&A) Will Be Collecting Samples From, Incl. The Florida Smelting Company - Buffalo Ave. Site (FSC Buffalo). FSC Buffalo Exists In An Urban, Industrial Area With Residential Areas To The North & South Approx. 1/4 Mile Away. The St. Johns River Is ~1/3 Mile To The East, & The Trout River Is ~1/2 Mile To The North. Bulk Fuel Storage Tank Farms Are Located To The Northeast & Southeast. The Old FSC Buffalo Site Appears To Exist On The Northwest Corner Of A Bulk Fuel Storage Area Containing 2 Large (500,000 gal. +) Storage Tanks On The Southeast Portion Of Site. Evergreen Ave Borders The Storage Area On The East. Fencing Surrounds The Storage Area Property (6' Chain Link w/ Barb-wire). A Railroad Spur Is Located Next To Site To The North, & May Actually Be Part Of The Historic FSC Buffalo Site. This Spur Is Also Fenced As Part Of The Facility North Of Site. Several (~4) Additional Above Ground Storage Tanks (10,000 - 50,000 gal.) Were Observed On This Site, Which Is Also Fenced. RR Tracks Exist To The North Of This Facility Also.

4/11/03 Cont.

No Drainage Features Were Observed Leaving Site. A Large Sewer Grate Was Observed On The Eastern Portion Of The Storage Facility, ~10 Feet East Of Buffalo Ave., Near The Entrance Road/Driveway. The Storage Facility Also Had Several Covered Bays For Filling Tanker Trucks Located Near The Center Of Site. A Small Bldg. Was Located To The Southeast Of The Loading Bays. One Horizontal Tank (Poss. Propane or LNG) Was Located Along The Northern Edge Of The Storage Facility, Where It Is Believed That FSC Buffalo Once Existed. A Tall, Slender Tank (Unk.) Is Also In This Area. Transfer Lines Go From This Area, Over The Fencing & RR Tracks, To The Facility To The North.

2004 - 2005

Access Issues Delay Field Sampling Event. Kanab & CSX Disagree On The Location Of The Former FSC Structure. Both Parties Eventually Permit Access - Kanab Will Split Samples From Their Property. CSX Only Requests Notification Of When Sampling Will Occur.

June 15, 2005

0800 Arrive At FSC Buffalo Ave Site. Hold Safety Mtg: Threats Are Trains, Slip/Trip, Heat Exhaustion.

0900 Meet With Dylan Morgan & David Dixon At The Main Support Terminals Facility At 6531 Evergreen. Hold Safety Mtg/Briefing.

0950 Collect Sampling Equip & Head Inside Terminal Property To Sample. Sampling Team In Terminal Is K. Patton & J. Sandlin Accompanied With Dylan Morgan & David Dixon (Coastal).

1007 Collect Soil Sample 16-SS Split With Kanab.
See Logbook 2 For Details.

1025 Collect Soil Sample 17-SS Split With Kanab.
SS-16 Located 4 Yds South Of Rail Post & 3 Yds East Of Western Fence.
17-SS Located 50' NNW Of N. Gate.

1043 Collect 18-SS @ Kanab. Sample Was Relocated Since Original Location Was Within Secondary Containment Area Of Gasoline Tanks.

June 15, 2005

New Loc. Moves SS-18 East To SS-19 Loc.
SS 19 Moves NW & SS-20 Moves NE

1100 Collect SS-19 100' West Of Evergreen Fenceline, 50' South Of Northern Fenceline

1123 Collect SS-20 @ Kanaks Collected 60' East Of Corner Of Bldg.

1140 Return To Staging Area & Begin To Secure For Lunch Break. Samples Remain On Ice.

1200 Break For Lunch

1300 Return To Site & Prepare To Collect Soil Samples. Team 1 Consists Of G. Kowalski; Team 2 Is K. Patton & J. Sanchez (See Log Book 2)

1350 Collect 09-SS / No Splits From CSX Prop. Sample Is 30' North Of Tracks, 100' West Of Evergreen. Soil Type Is A Black Sand Topsoil With Grey Sand. Vegetation Is Brown/Dry To South & Green (Different Type To North).
GPS: 30°22' 39.9"N, 81°38' 19.5"W.

1415 Collect Soil 08-SS & Dupe 21-SS From Same Loc 35' N of Tracks, 10' West Of Eastern Track Switch, 20' South Of Fence.
GPS: 30°22' 39.8"N, 81°38' 21.2"W

Soil Type Is A Black Top Soil W/ Grey Sand. Normal Veg.

1445 Collect SS-13 Near Vegetated Area At East Side Of Site, 15' North Of Fence At Kanaks. Debris Located In Veg. Area (Boat, A/C, Tires, Metal Scrap). Soil Type Is A Grey Sand. Vegetation Is Sparse On South Side Of Tracks.
GPS: 30° 22' 38.4"N, 81° 38' 21.0"

1515 Begin Processing Samples For Shipment.

1700 One Team Heads To UPS With All Samples Collected Today. Second Team Heads To Purchase New Planner. End Of Day.

June 16, 2005

Cond: Hot, Humid, 85-95°

0800 Arrive At Site & Set Up. ——

No Consultants On Site From CSX.

All Remaining Samples Are From CSX Prop.

0830 Collect 05-SS 20' North Kanab Fence, 30' South Of RR Tracks. Soil Type Is A Moist Grey Sand / No Organics. No / Sparse Vegetation In This Area.

See Logbook 2 For GPS Loc. Of 02-05-SS Samples ——

0840 Collect 04-SS 20' North Of Kanab Fence, In Line With Fire Hydrant. Soil Type Is A Grey Sand. Vegetation Is Sparse. Loc Is ~150 East Of Buffalo Ave. No Observations Of Interest (No Footings, Concrete Pads, Or Other Items To Suggest A Building Was Located Here. ——

0900 Collect 02-SS 25' North Of Tracks In Line With Fire Hydrant (Due North Of 04) ~150' East Of Buffalo Ave. Vegetation Is Present Here And Appears Healthy. Soil Type Is A Thin Layer Of Black Grey Top Soil (1") With Grey Sand Beneath. No Signs / Observations Of Former Bldg.

6/16/05

0915 Collect 03-SS 30' North Of Tracks, North Of 05-SS, Due North Of Center Of Tank Farm @ Kanab. Thin Layer Of Top Soil (0.5") Covers Grey Sand. Veg. Normal / Healthy.

0930 Troubleshoot Power Issues To Laptop Computer (Wont Run w/out Power Source & Batt. Has Died.)

0955 Able To Remedy Computer Problem & Continue Running FZ.

1005 Collect SS 07 25' North Of Tracks, 20' South Of Fence Corner Of Phillips Prop. Veg. Is Normal. Soil Type Is Grey / Black Sand, Slightly Rocky Intermixed. ——

GPS: 30° 22' 39.7" N, 81° 38' 24.0"

This Area Slightly More Rocky / Gravel Than Other Areas. ——

Loc Is Due North Of Western Edge Of Bldg @ Kanab. ——

1020 Collect 11-SS & Dup 22-SS From 30' North Of Kanab Fence, Along In Line With Western Edge Of Bldg. Soil Type Is A Grey Sand, Veg Is Sparse In This Sandy Area.

6/16/05

GPS: 30° 22' 38.0"N, 81° 38' 24.0"W.

1050 Begin Processing/Packing Samples For Shipment.

1210 Depart Site For Lunch.

1330 Arrive Back At Hotel & Determine Best Way To Keep Samples Cold In The Extreme Heat Is To Retain The Samples As Long As Possible, Then Relinquish Them To UPS To Avoid Having Them Sit In Hot Trucks Or On Loading Docks.

1700 Keep Samples At Hotel Then Have UPS Pick Up Between 1700-1800 (As Late As Can Be Scheduled.)

End Of Field Sampling Event.

Fri. June 17, 2005

Sampling Team Demobilizes Back To Atlanta (Marietta); Cleans & Returns Rental Equipment And Rental Vehicles.

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

LEVEL

All-Weather Notebook
No. 311

Buffalo Ave Site (FSC Buffalo)

Florida Smelting Company
Jacksonville, Duval County, FL
U.S. EPA ID No. FLN000407555
KANEB Terminals

4 5/8" x 7" - 48 Numbered Pages

LogBook #2

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

Name Jorge A. Sanchez
Senior Project Chemist

Address 840 Kennesaw Ave. Suite B7
Marietta, Georgia 30060

Phone 673-355-5550

Project Florida Smelting Company.
Jacksonville, Duval County, Florida
U.S. EPA ID. No. FL N000407555
KANEB Terminals.

Clear Vinyl Protective Slipcovers (Item No. 30) are available for this style of notebook. Helps protect your notebook from wear & tear. Contact your dealer or the J. L. Darling Corporation.

CONTENTS

06/15/05

07:30 Conducted Safety Tailgate Meeting.
- Stay clear off Rail Road Track
- Watch for uneven grounds
- Drink plenty of fluids Heat Exhaustion
- Slips, trips and falls

08:15 Arrived at site area and set-up materials and equipment ready for sampling

Calibration of Field Analytical Equipment

Component	Concentration	Precalibrating	Post Cal Reading
Isobutylene	100 ppm	98.2 ppm	100 ppm
CO	50 ppm	80 ppm	53 ppm
VOC			
H_2S	25 ppm	21 ppm	25 ppm
LEL	50%	51%	50%
O^2	20.9%	20.6%	20.8%

Weather: High 95°F = Temperature
100% = Humidity
Conditions = Clear skies afternoon thunderstorms

09:00 Reported to Kaneb Terminals aka ST Services for signing in procedures and debriefing safety and security procedures. Mr. Dylan T. Morgan, P.G. Senior Manager - Environmental Remediation + Regulatory Oversight Health, Environment,

6/15/05

Safety + Security Division Kaneb conducted the safety briefing at the terminal facility office. Dave Davidson with tag along for split samples

09:40 Completed briefing with Kaneb Left office via set-up sampling area.

10:00 Inside the Tank Farm area near to commence sampling even on secure grounds along with Kaneb officer.

10:07 Collecting Sample ID # 16-SS.

Location: Tank farm grassy area east of Buffalo Avenue. Fenced area. Across from 50th Street and Buffalo Avenue. West East from #2 Tracks corner of Fenced area. (Next to rail Crossing)

GPS Coordinates - N 30° 22' 36.7"
W 081° 38' 27.3"

Soil Type - Silty Sandy Light Brown Soil

Field Analytical - CO = 0 ppm   LEL = 0%
VOC = 0.0 ppm O^2 = 20.8%
H_2S = 0 ppm

10:25 Collecting Sample ID# 17-SS.

Location: Tank farm grassy area east of Buffalo ST And 50th Street Intersection. Next to (right) security Fence. Next gas Tank (propane bullet Tank)

6/15/05

GPS Coordinates N 30° 22' 36.2"
~~W 081° 26~~
W 081° 38' 26.0"
Soil Type: Silty Sandy Light Brown Soil
Field Analytical: CO = 0 ppm, LEL = 0%
VOC = 0 ppm, O^2 = 20.9%
H_2S = 0 ppm
10:43 Collecting Sample ID # 18-SS
Location: East grassy area. West from Evergreen Avenue. North-East from AST.
GPS Coordinates N 30° 22 36.2"
W 081° 38' 20.1"
Soil Type: Silty Sandy Light Brown Soil.
Field Analytical: CO = 0 ppm, LEL = 0%
VOC = 0 ppm, O^2 = 20.9%
H_2S = 0 p.pm
11:00 Collecting Sample ID # 19-SS
Location: North end grassy area. West from Evergreen Road & East (far East) from Annex I Warehouse. About 15 yards from North Fence.
GPS Coordinates N 30° 22' 37.9"
W 081° 38' 20.1"
Soil Type Silty Sandy Light Brown Soil
Field Analytical CO = 0 ppm, LEL = 1%
VOC = 0 ppm O^2 = 20.9%
H_2S = 0 ppm

6/15/05

11:23 Collecting Sample ID # 20-SS
Location: 20 yards East from ANNEX I Bldg and about 15 yards South from North Fence Grassy area Parallell from ASTs
GPS Coordinates N 30° 22' 38.0"
W 081° 38' 21.4"
Soil Type: Silty Sandy Light Brown Soil
Field Analytical: CO = 0.0 ppm, LEL = 1%
VOC = 0.0 ppm O^2 = 21.0%
H_2S = 0.0 ppm
13:35 Collecting Sample ID # 01-SS.
Location: about 100 yards West of Buffalo Avenue South from Rail Road Tracks. Inside Opening Area from Tree Line. Shortcut through To 50th street.
GPS Coordinates. N 30° 22' 37.6"
W 081° 38' 33.5"
Soil Type: Silty Sandy Dark Brown Soil
Field Analytical: CO = 0 ppm, LEL = 0%
VOC = 0.0 ppm O^2 = 20.9%
H_2S = 0.0 ppm
13:55 Collected Sample ID # 01-SB. Located at the same position from Sample ID# 01-SS.
Soil Type: Very fine Grain (Sugar Sand), Sand Tan. Low

6 6/15/05

Photo Log

Photo #	Date	Site	Description
59	6/15/05	KAWEB	01SS/01SB East RR Track
60	"	"	01SS/01SB Tree Line South Box
61	"	"	15SS Between 50th Street + RR Track
62	"	"	~~#~~14SS West Buffalo Ave
63	"	"	12SS North Fence Corner ANNEX 1
64	"	"	13SS North Fence East ANNEX
65	"	"	08SS North RR Track
66	"	"	09SS North East 22RT
67	6/16/05		05-SB/06-SB North East
68	"		04SS North East
69	"		04-SB "
70	"		02SS (Parallel To 04SS)
71	"		02-SB "
72			03-SS (Parallel To 05-SS)
73			03-SB (parallel To 05-SB)
74			10-SS (Buffalo Ave)
75			06-SS (Between Spur)
76			07SS (Parallel To 011-SS)
			11SS/22SS (North-North West ANNEX 1)

6/15/05 7

moisture. Continue To auger to find saturated Sand and collect sample. Coordinates are the same as 01-SS and field analytical the same.

14:07 Collecting Sample ID# ~~NS~~ 15SS

Location: East of Buffalo Avenue between 50th Street and Rail Road Track. Inside Tree Line.

GPS Coordinates ~~N 30°22'38.3~~
N 30° 22' 36.3"
W 081° 38' 28.8"

Soil Type: Silty Sandy Brown Soil

Field Analytical: CO = 0ppm, LEL = 0%, VOC = 0ppm, O^2 = 20.9%, H_2S = 0ppm

14:45 Collecting Sample ID# 14SS

Location: West from Buffalo Avenue 22 feet south from Rail Road Crossing Warning Lights.

GPS Coordinates N 30° 22' 38.5"
W 081° 38' 28.8"

Soil Type: Silty Sandy Dark Brown Soil

Field Analytical: CO = 0.0ppm, LEL = 0%, VOC = 0.0ppm, O^2 = 20.9%, H_2S = 0.0ppm

6/15, 16/05

15:05 Collecting Sample ID # 1255.
Located North-North East from ANNEX I building 20' feet North from the Fence and 5' feet inside.
GPS Coordinates: N 30° 22' 38.6"
W 081° 38' 22.2"
Soil Type Silty Sandy Light Brown Soil to Dark Brown Soil
Field Analytical: CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm O^2 = 20.9%
H_2S = 0.0ppm
17:45 Delivered 3 Sample coolers to UPS for overnight delivery to Analytical Lab.
18:10 Arrived at hotel Comfort Suites

06/16/05

07:00 Left hotel via site area CSX.
Conducted Tailgate safety meeting.
- Drink plenty of fluids keep hydrate
- Watch for uneven grounds and sharp objects.
- Watch for Rail Road Traffic.
- Slips, trips + falls. Use proper bending techniques to pick up materials.

6/16/05

08:00 Arrived at site area and began to set-up materials and equipment.
08:30 Collecting Sample ID # 05-SB
Located 15' feet North of Perimeter Fence and AST (Small ASTs) retaining dike.
GPS Coordinates N 30° 22' 38.6"
W 081° 38' 25.6"
Soil Type Silty Sandy ~~Dark~~ Light Brown Soil
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
In addition collected Duplicate Sample ID # 06-SB
08:50 Collecting Sample ID# 04-SB
Location: East of Small AST farm. 15' feet North of Perimeter Fence. North of Fire Hydrant
GPS Coordinates: N 30° 22' 38.6"
W 081° 38' 26.5"
Soil Type Silty Sandy ~~Dark~~ Light Brown Soil. Top layer consists of Sand white/Tan.
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm
Weather: Temperature = Low 77°F high = 96°F
Humidity = 100%
Conditions: Partially cloudy. Sctd. Showers.

6/16/05

Field Analytical: CO = 0.0ppm, H_2S = 0ppm
VOC = 0.0ppm, LEL = 0%, O^2 = 20.9%

09:10 - Collecting Sample ID # 02-SB
Location Parallell To Sample ID # 04-SB
Across from Rail Road Track in between the last Two Spurs.
GPS Coordinates N 30° 22' 39.6"
W 081° 38' 26.4"
Soil type Silty Sandy Brown Soil

09:25 Collecting Sample ID# 03-SB
Location: Parallell To Sample ID # 05-SB
North Rail Road tracks in between the last Two Spurs
GPS Location N 30° 22' 39.7"
W 081° 38' 25.6"
Soil type Silty Sandy Light tan, White Sand.
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm

09:55 Collecting Sample ID# 10-SS
Location. North-North West Corner of KANEB Tank Farm Perimeter Fence.
Next to Buffalo Avenue (28' feet), and 18' feet Diagonal of Rail Road Crossing Tracks 3 Warning Signal lights.
GPS Coordinates: N 30° 22' 38.6"
W 081° 38' 28.0"

6/16/05

Soil Type: Silty Sandy Dark Brown
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm

10:02 Collecting Sample ID # 06-SS.
Location Parallell to Sample ID # 10-SS.
Between Last Two North Spurs
25' Away from middle of Track on each side of the Spur. In between Two RailRoad Track Crossing #3 Warning Lights for Buffalo Avenue, 50' feet away or East of Buffalo Avenue.
GPS Coordinates N 30° 22' 39.8"
W 081° 38' 28.1"
Soil type Silty Sandy Brown Soil
Field Analytical CO = 0.0ppm, LEL = 0%
VOC = 0.0ppm, O^2 = 20.9%
H_2S = 0.0ppm

[signature] 6/16/05

Key : SFo,i=Cancer Slope Factor oral, inhalation RfDo,i=Reference Dose oral, inhalation i=IRIS p=PPRTV c=California EPA n=NCEA h=HEAST x=Withdrawn r=Route-extrapolation ca=Cancer PRG nc= Noncancer PRG ca* (where: nc PRG < 100X ca PRG)
ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
8.7E-03	i	4.0E-03	i	8.7E-03	r	4.0E-03	r		0.1	30560-19-1	Acephate	5.6E+01	ca**	2.0E+02	ca*	7.7E-01	ca*	7.7E+00	ca*		
				7.7E-03	i	2.6E-03	i	y		75-07-0	Acetaldehyde	1.1E+01	ca**	2.3E+01	ca**	8.7E-01	ca*	1.7E+00	ca		
		2.0E-02	i			2.0E-02	r		0.1	34256-82-1	Acetochlor	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		9.0E-01	i			9.0E-01	r	y		67-64-1	**Acetone**	1.4E+04	nc	5.4E+04	nc	3.3E+03	nc	5.5E+03	nc	1.6E+01	8.0E-01
		8.0E-04	h			8.0E-04	r		0.1	75-86-5	Acetone cyanohydrin	4.9E+01	nc	4.9E+02	nc	2.9E+00	nc	2.9E+01	nc		
		1.7E-02	r			1.7E-02	i	y		75-05-8	Acetonitrile	4.2E+02	nc	1.8E+03	nc	6.2E+01	nc	1.0E+02	nc		
		5.0E-04	i			5.7E-06	i	y		107-02-8	**Acrolein**	1.0E-01	nc	3.4E-01	nc	2.1E-02	nc	4.2E-02	nc		
4.5E+00	i	2.0E-04	i	4.5E+00	i	2.0E-04	r		0.1	79-06-1	Acrylamide	1.1E-01	ca	3.8E-01	ca	1.5E-03	ca	1.5E-02	ca		
		5.0E-01	i			2.9E-04	i		0.1	79-10-7	Acrylic acid	2.9E+04	nc	1.0E+05	max	1.0E+00	nc	1.8E+04	nc		
5.4E-01	i	1.0E-03	h	2.4E-01	i	5.7E-04	i	y		107-13-1	Acrylonitrile	2.1E-01	ca*	4.9E-01	ca*	2.8E-02	ca*	3.9E-02	ca*		
1.0E+00	r			1.0E+00	c			y			**"CAL-Modified PRG"**	5.5E-02	ca	1.2E-01	ca	6.7E-03	ca	1.1E-02	ca		
8.1E-02	h	1.0E-02	i	8.0E-02	r	1.0E-02	r		0.1	15972-60-8	Alachlor	6.0E+00	ca	2.1E+01	ca	8.4E-02	ca	8.4E-01	ca		
		1.5E-01	i			1.5E-01	r		0.1	1596-84-5	Alar	9.2E+03	nc	9.2E+04	nc	5.5E+02	nc	5.5E+03	nc		
		1.0E-03	i			1.0E-03	r		0.1	116-06-3	Aldicarb	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		1.0E-03	i			1.0E-03	r		0.1	1646-88-4	Aldicarb sulfone	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
1.7E+01	i	3.0E-05	i	1.7E+01	i	3.0E-05	r		0.1	309-00-2	Aldrin	2.9E-02	ca*	1.0E-01	ca	3.9E-04	ca	4.0E-03	ca	5.0E-01	2.0E-02
		2.5E-01	i			2.5E-01	r		0.1	74223-64-6	Ally	1.5E+04	nc	1.0E+05	max	9.1E+02	nc	9.1E+03	nc		
		5.0E-03	i			5.0E-03	r		0.1	107-18-6	Allyl alcohol	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.9E-04	r			2.9E-04	i		0.1	107-05-1	**Allyl chloride**	1.7E+01	nc	1.8E+02	nc	1.0E+00	nc	1.0E+01	nc		
		1.0E+00	p			1.4E-03	p			7429-90-5	Aluminum	7.6E+04	nc	1.0E+05	max	5.1E+00	nc	3.6E+04	nc		
		4.0E-04	i							20859-73-8	Aluminum phosphide	3.1E+01	nc	4.1E+02	nc			1.5E+01	nc		
		3.0E-04	i			3.0E-04	r		0.1	67485-29-4	Amdro	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
		9.0E-03	i			9.0E-03	r		0.1	834-12-8	Ametryn	5.5E+02	nc	5.5E+03	nc	3.3E+01	nc	3.3E+02	nc		
		2.0E-04	n			2.0E-04	r		0.1	1321-12-6	**Aminodinitrotoluene**	1.2E+01	nc	1.2E+02	nc	7.3E-01	nc	7.3E+00	nc		
		7.0E-02	h			7.0E-02	r		0.1	591-27-5	m-Aminophenol	4.3E+03	nc	4.3E+04	nc	2.6E+02	nc	2.6E+03	nc		
		2.0E-05	h			2.0E-05	r		0.1	504-24-5	4-Aminopyridine	1.2E+00	nc	1.2E+01	nc	7.3E-02	nc	7.3E-01	nc		
		2.5E-03	i			2.5E-03	r		0.1	33089-61-1	Amitraz	1.5E+02	nc	1.5E+03	nc	9.1E+00	nc	9.1E+01	nc		
						2.9E-02	i			7664-41-7	Ammonia					1.0E+02	nc				
		2.0E-01	i						0.1	7773-06-0	Ammonium sulfamate	1.2E+04	nc	1.0E+05	max			7.3E+03	nc		
5.7E-03	i	7.0E-03	p	5.7E-03	r	2.9E-04	i		0.1	62-53-3	Aniline	8.5E+01	ca**	3.0E+02	ca*	1.0E+00	nc	1.2E+01	ca*		
		4.0E-04	i							7440-36-0	Antimony and compounds	3.1E+01	nc	4.1E+02	nc			1.5E+01	nc	5.0E+00	3.0E-01
		1.3E-02	i			1.3E-02	r		0.1	74115-24-5	Apollo	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
2.5E-02	i	5.0E-02	h	2.5E-02	i	5.0E-02	r		0.1	140-57-8	Aramite	1.9E+01	ca	6.9E+01	ca	2.7E-01	ca	2.7E+00	ca		
1.5E+00	i	3.0E-04	i	1.5E+01	i				0.03	7440-38-2	Arsenic	3.9E-01	ca*	1.6E+00	ca	4.5E-04	ca	4.5E-02	ca	2.9E+01	1.0E+00
9.5E+00	c			1.2E+01	c				0.03		**"CAL-Modified PRG"**	6.2E-02	ca	2.5E-01	ca	5.6E-04	ca	7.1E-03	ca		
						1.4E-05	i			7784-42-1	Arsine (see arsenic for cancer endpoint)					5.2E-02	nc				
		9.0E-03	i			9.0E-03	r		0.1	76578-14-8	Assure	5.5E+02	nc	5.5E+03	nc	3.3E+01	nc	3.3E+02	nc		
		5.0E-02	i			5.0E-02	r		0.1	3337-71-1	Asulam	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
2.2E-01	h	3.5E-02	i	2.2E-01	r	3.5E-02	r		0.1	1912-24-9	Atrazine	2.2E+00	ca	7.8E+00	ca	3.1E-02	ca	3.0E-01	ca		
		4.0E-04	i			4.0E-04	r		0.1	71751-41-2	Avermectin B1	2.4E+01	nc	2.5E+02	nc	1.5E+00	nc	1.5E+01	nc		
1.1E-01	i			1.1E-01	i				0.1	103-33-3	Azobenzene	4.4E+00	ca	1.6E+01	ca	6.2E-02	ca	6.1E-01	ca		
		7.0E-02	i			1.4E-04	h			7440-39-3	Barium and compounds	5.4E+03	nc	6.7E+04	nc	5.2E-01	nc	2.6E+03	nc	1.6E+03	8.2E+01

Reference 12

Key : SFo,i=Cancer Slope Factor oral, inhalation RfDo,i=Reference Dose oral, inhalation i=IRIS p=PPRTV c=California EPA n=NCEA h=HEAST x=Withdrawn r=Route-extrapolation ca=Cancer PRG nc= Noncancer PRG ca* (where: nc PRG < 100X ca PRG) ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		4.0E-03	i			4.0E-03	r		0.1	114-26-1	Baygon	2.4E+02	nc	2.5E+03	nc	1.5E+01	nc	1.5E+02	nc		
		3.0E-02	i			3.0E-02	r		0.1	43121-43-3	Bayleton	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		2.5E-02	i			2.5E-02	r		0.1	68359-37-5	Baythroid	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		3.0E-01	i			3.0E-01	r		0.1	1861-40-1	Benefin	1.8E+04	nc	1.0E+05	max	1.1E+03	nc	1.1E+04	nc		
		5.0E-02	i			5.0E-02	r		0.1	17804-35-2	Benomyl	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		3.0E-02	i			3.0E-02	r		0.1	25057-89-0	Bentazon	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		1.0E-01	i			1.0E-01	r		0.1	100-52-7	Benzaldehyde	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
5.5E-02	i	4.0E-03	i	2.7E-02	i	8.6E-03	i	y		71-43-2	**Benzene**	6.4E-01	ca*	1.4E+00	ca*	2.5E-01	ca	3.5E-01	ca	3.0E-02	2.0E-03
2.3E+02	i	3.0E-03	i	2.3E+02	i	3.0E-03	r		0.1	92-87-5	Benzidine	2.1E-03	ca	7.5E-03	ca	2.9E-05	ca	2.9E-04	ca		
		4.0E+00	i			4.0E+00	r		0.1	65-85-0	Benzoic acid	1.0E+05	max	1.0E+05	max	1.5E+04	nc	1.5E+05	nc	4.0E+02	2.0E+01
1.3E+01	i			1.3E+01	r				0.1	98-07-7	Benzotrichloride	3.7E-02	ca	1.3E-01	ca	5.2E-04	ca	5.2E-03	ca		
		3.0E-01	h			3.0E-01	r		0.1	100-51-6	Benzyl alcohol	1.8E+04	nc	1.0E+05	max	1.1E+03	nc	1.1E+04	nc		
1.7E-01	i	2.9E-03	r	1.7E-01	r	2.9E-03	n	y		100-44-7	Benzyl chloride	8.9E-01	ca*	2.2E+00	ca	4.0E-02	ca	6.6E-02	ca		
		2.0E-03	i	8.4E+00	i	5.7E-06	i			7440-41-7	Beryllium and compounds	1.5E+02	nc	1.9E+03	ca**	8.0E-04	ca*	7.3E+01	nc	6.3E+01	3.0E+00
		1.0E-04	i			1.0E-04	r		0.1	141-66-2	Bidrin	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		1.5E-02	i			1.5E-02	r		0.1	82657-04-3	Biphenthrin (Talstar)	9.2E+02	nc	9.2E+03	nc	5.5E+01	nc	5.5E+02	nc		
		5.0E-02	i			5.0E-02	r	y		92-52-4	**1,1-Biphenyl**	3.0E+03	nc	2.3E+04	nc	1.8E+02	nc	3.0E+02	nc		
1.1E+00	i			1.1E+00	i			y		111-44-4	Bis(2-chloroethyl)ether	2.2E-01	ca	5.8E-01	ca	6.1E-03	ca	1.0E-02	ca	4.0E-04	2.0E-05
7.0E-02	x	4.0E-02	i	3.5E-02	x	4.0E-02	r	y		108-60-1	Bis(2-chloroisopropyl)ether	2.9E+00	ca	7.4E+00	ca	1.9E-01	ca	2.7E-01	ca		
2.2E+02	i			2.2E+02	i			y		542-88-1	Bis(chloromethyl)ether	1.9E-04	ca	4.3E-04	ca	3.1E-05	ca	5.2E-05	ca		
7.0E-02	x	4.0E-02	i	3.5E-02	x	4.0E-02	r	y		108-60-1	Bis(2-chloro-1-methylethyl)ether	2.9E+00	ca	7.4E+00	ca	1.9E-01	ca	2.7E-01	ca		
1.4E-02	i	2.0E-02	i	1.4E-02	r	2.0E-02	r		0.1	117-81-7	Bis(2-ethylhexyl)phthalate (DEHP)	3.5E+01	ca*	1.2E+02	ca	4.8E-01	ca	4.8E+00	ca		
		5.0E-02	i			5.0E-02	r		0.1	80-05-7	Bisphenol A	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		2.00E-01	i			5.7E-03	h			7440-42-8	Boron	1.6E+04	nc	1.0E+05	max	2.1E+01	nc	7.3E+03	nc		
						2.0E-04	h			7637-07-2	Boron trifluoride					7.3E-01	nc				
7.0E-01	i	4.0E-03	i	7.0E-01	r	4.0E-03	r		0.1	15541-45-4	**Bromate**	6.9E-01	ca	2.5E+00	ca	9.6E-03	ca	9.6E-02	ca		
		2.0E-02	p			2.9E-03	p	y		108-86-1	Bromobenzene	2.8E+01	nc	9.2E+01	nc	1.0E+01	nc	2.0E+01	nc		
6.2E-02	i	2.0E-02	i	6.2E-02	r	2.0E-02	r	y		75-27-4	Bromodichloromethane	8.2E-01	ca	1.8E+00	ca	1.1E-01	ca	1.8E-01	ca	6.0E-01	3.0E-02
7.9E-03	i	2.0E-02	i	3.9E-03	i	2.0E-02	r		0.1	75-25-2	Bromoform (tribromomethane)	6.2E+01	ca*	2.2E+02	ca*	1.7E+00	ca*	8.5E+00	ca*	8.0E-01	4.0E-02
		1.4E-03	i			1.4E-03	i	y		74-83-9	Bromomethane (Methyl bromide)	3.9E+00	nc	1.3E+01	nc	5.2E+00	nc	8.7E+00	nc	2.0E-01	1.0E-02
		5.0E-03	h			5.0E-03	r		0.1	2104-96-3	Bromophos	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.0E-02	i			2.0E-02	r		0.1	1689-84-5	Bromoxynil	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		2.0E-02	i			2.0E-02	r		0.1	1689-99-2	Bromoxynil octanoate	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
1.1E-01	r	5.7E-04	r	1.1E-01	i	5.7E-04	i	y		106-99-0	**1,3-Butadiene**	5.8E-02	ca*	1.2E-01	ca*	6.1E-02	ca*	1.0E-01	ca*		
6.0E-01	r	5.7E-03	r	6.0E-01	c	5.7E-03	c	y		106-99-0	**"CAL-Modified PRG"**	1.1E-02	ca	2.3E-02	ca	1.1E-02	ca	1.9E-02	ca		
		1.0E-01	i			2.8E-03	n		0.1	71-36-3	1-Butanol	6.1E+03	nc	6.1E+04	nc	9.5E+00	nc	3.6E+03	nc	1.7E+01	9.0E-01
		5.0E-02	i			5.0E-02	r		0.1	2008-41-5	Butylate	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		4.0E-02	n			4.0E-02	r	y		104-51-8	n-Butylbenzene	2.4E+02	sat	2.4E+02	sat	1.5E+02	nc	2.4E+02	nc		
		4.0E-02	n			4.0E-02	r	y		135-9-88	sec-Butylbenzene	2.2E+02	sat	2.2E+02	sat	1.5E+02	nc	2.4E+02	nc		
		4.0E-02	n			4.0E-02	r	y		98-06-6	tert-Butylbenzene	3.9E+02	sat	3.9E+02	sat	1.5E+02	nc	2.4E+02	nc		
		2.0E-01	i			2.0E-01	r		0.1	85-68-7	Butyl benzyl phthalate	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc	9.3E+02	8.1E+02
		1.0E+00	i			1.0E+00	r		0.1	85-70-1	Butylphthalyl butylglycolate	6.1E+04	nc	1.0E+05	max	3.7E+03	nc	3.6E+04	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		5.0E-04	i	6.3E+00	i				0.001	7440-43-9	Cadmium and compounds	3.7E+01	nc	4.5E+02	nc	1.1E-03	ca	1.8E+01	nc	8.0E+00	4.0E-01
		5.0E-01	i			5.0E-01	r		0.1	105-60-2	Caprolactam	3.1E+04	nc	1.0E+05	max	1.8E+03	nc	1.8E+04	nc		
8.6E-03	h	2.0E-03	i	8.6E-03	r	2.0E-03	r		0.1	2425-06-1	Captafol	5.7E+01	ca**	2.0E+02	ca**	7.8E-01	ca**	7.8E+00	ca**		
3.5E-03	h	1.3E-01	i	3.5E-03	r	1.3E-01	r		0.1	133-06-2	Captan	1.4E+02	ca*	4.9E+02	ca	1.9E+00	ca	1.9E+01	ca		
		1.0E-01	i			1.1E-01	r		0.1	63-25-2	Carbaryl	6.1E+03	nc	6.2E+04	nc	4.0E+02	nc	3.6E+03	nc		
2.0E-02	h			2.0E-02	r				0.1	86-74-8	Carbazole	2.4E+01	ca	8.6E+01	ca	3.4E-01	ca	3.4E+00	ca	6.0E-01	3.0E-02
		5.0E-03	i			5.0E-03	r		0.1	1563-66-2	Carbofuran	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		1.0E-01	i			2.0E-01	i	y		75-15-0	Carbon disulfide	3.6E+02	nc	7.2E+02	sat	7.3E+02	nc	1.0E+03	nc	3.2E+01	2.0E+00
1.3E-01	i	7.0E-04	i	5.3E-02	i	7.0E-04	r	y		56-23-5	Carbon tetrachloride	2.5E-01	ca**	5.5E-01	ca*	1.3E-01	ca*	1.7E-01	ca*	7.0E-02	3.0E-03
		1.0E-02	i			1.0E-02	r		0.1	55285-14-8	Carbosulfan	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		1.0E-01	i			1.0E-01	r		0.1	5234-68-4	Carboxin	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		1.5E-02	i			1.5E-02	r		0.1	133-90-4	Chloramben	9.2E+02	nc	9.2E+03	nc	5.5E+01	nc	5.5E+02	nc		
4.0E-01	h			4.0E-01	r				0.1	118-75-2	Chloranil	1.2E+00	ca	4.3E+00	ca	1.7E-02	ca	1.7E-01	ca		
3.5E-01	i	5.0E-04	i	3.5E-01	i	2.0E-04	i		0.04	12789-03-6	Chlordane (technical)	1.6E+00	ca*	6.5E+00	ca*	1.9E-02	ca*	1.9E-01	ca*	1.0E+01	5.0E-01
		2.0E-02	i			2.0E-02	r		0.1	90982-32-4	Chlorimuron-ethyl	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		1.0E-01	i			5.7E-05	n			7782-50-5	Chlorine					2.1E-01	nc				
		3.0E-02	i			5.7E-05	i			10049-04-4	Chlorine dioxide					2.1E-01	nc				
		2.0E-03	h			2.0E-03	r		0.1	79-11-8	Chloroacetic acid	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		8.6E-06	r			8.6E-06	i	y		532-27-4	2-Chloroacetophenone	3.3E-02	nc	1.1E-01	nc	3.1E-02	nc	5.2E-02	nc		
		4.0E-03	i			4.0E-03	r		0.1	106-47-8	4-Chloroaniline	2.4E+02	nc	2.5E+03	nc	1.5E+01	nc	1.5E+02	nc	7.0E-01	3.0E-02
		2.0E-02	i			1.7E-02	n	y		108-90-7	Chlorobenzene	1.5E+02	nc	5.3E+02	nc	6.2E+01	nc	1.1E+02	nc	1.0E+00	7.0E-02
2.7E-01	h	2.0E-02	i	2.7E-01	h	2.0E-02	r		0.1	510-15-6	Chlorobenzilate	1.8E+00	ca	6.4E+00	ca	2.5E-02	ca	2.5E-01	ca		
		2.0E-01	h			2.0E-01	r		0.1	74-11-3	p-Chlorobenzoic acid	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc		
		2.0E-02	h			2.0E-02	r		0.1	98-56-6	4-Chlorobenzotrifluoride	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		2.0E-02	h			2.0E-03	h	y		126-99-8	2-Chloro-1,3-butadiene	3.6E+00	nc	1.2E+01	nc	7.3E+00	nc	1.4E+01	nc		
		4.0E-01	h			4.0E-01	r	y		109-69-3	1-Chlorobutane	4.8E+02	sat	4.8E+02	sat	1.5E+03	nc	2.4E+03	nc		
		1.4E+01	r			1.4E+01	i	y		75-68-3	1-Chloro-1,1-difluoroethane (HCFC-142b)	3.4E+02	sat	3.4E+02	sat	5.2E+04	nc	8.7E+04	nc		
		1.4E+01	r			1.4E+01	i	y		75-45-6	Chlorodifluoromethane	3.4E+02	sat	3.4E+02	sat	5.1E+04	nc	8.5E+04	nc		
2.9E-03	n	4.0E-01	n	2.9E-03	r	2.9E+00	i	y		75-00-3	Chloroethane	3.0E+00	ca	6.5E+00	ca	2.3E+00	ca	4.6E+00	ca		
		1.0E-02	i	8.1E-02	i	1.4E-02	n	y		67-66-3	**Chloroform**	2.2E-01	ca	4.7E-01	ca	8.3E-02	ca	1.7E-01	ca	6.0E-01	3.0E-02
3.1E-02	c			1.9E-02	c			y			"CAL-Modified PRG"	9.4E-01	ca	2.0E+00	ca	3.5E-01	ca	5.3E-01	ca		
		2.6E-02	r			2.6E-02	i	y		74-87-3	**Chloromethane (methyl chloride)**	4.7E+01	nc	1.6E+02	nc	9.5E+01	nc	1.6E+02	nc		
5.8E-01	h			5.8E-01	r				0.1	95-69-2	4-Chloro-2-methylaniline	8.4E-01	ca	3.0E+00	ca	1.2E-02	ca	1.2E-01	ca		
4.6E-01	h			4.6E-01	r				0.1	3165-93-3	4-Chloro-2-methylaniline hydrochloride	1.1E+00	ca	3.7E+00	ca	1.5E-02	ca	1.5E-01	ca		
		8.0E-02	i			8.0E-02	r	y		91-58-7	beta-Chloronaphthalene	4.9E+03	nc	2.3E+04	nc	2.9E+02	nc	4.9E+02	nc		
9.7E-03	p	1.0E-03	p	9.7E-03	r	2.0E-05	p	y		88-73-3	o-Chloronitrobenzene	1.4E+00	nc**	4.5E+00	nc**	7.3E-02	nc**	1.5E-01	nc**		
6.7E-03	p	1.0E-03	p	6.7E-03	r	1.7E-04	p	y		100-00-5	p-Chloronitrobenzene	1.0E+01	nc**	3.7E+01	nc**	6.2E-01	nc**	1.2E+00	nc**		
		5.0E-03	i			5.0E-03	r	y		95-57-8	2-Chlorophenol	6.3E+01	nc	2.4E+02	nc	1.8E+01	nc	3.0E+01	nc	4.0E+00	2.0E-01
		2.9E-02	r			2.9E-02	h	y		75-29-6	2-Chloropropane	1.7E+02	nc	5.9E+02	nc	1.0E+02	nc	1.7E+02	nc		
1.1E-02	h	1.5E-02	i	1.1E-02	r	1.5E-02	r		0.1	1897-45-6	Chlorothalonil	4.4E+01	ca*	1.6E+02	ca*	6.1E-01	ca*	6.1E+00	ca*		
		2.0E-02	i			2.0E-02	r	y		95-49-8	o-Chlorotoluene	1.6E+02	nc	5.6E+02	nc	7.3E+01	nc	1.2E+02	nc		
		2.0E-01	i			2.0E-01	r		0.1	101-21-3	Chlorpropham	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc		

Key : SFo,i=Cancer Slope Factor oral, inhalation RfDo,i=Reference Dose oral, inhalation i=IRIS p=PPRTV c=California EPA n=NCEA h=HEAST x=Withdrawn r=Route-extrapolation ca=Cancer PRG nc= Noncancer PRG ca* (where: nc PRG < 100X ca PRG) ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1. (mg/kg)
		3.0E-03	i			3.0E-03	r		0.1	2921-88-2	Chlorpyrifos	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
		1.0E-02	h			1.0E-02	r		0.1	5598-13-0	Chlorpyrifos-methyl	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		5.0E-02	i			5.0E-02	r		0.1	64902-72-3	Chlorsulfuron	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		8.0E-04	h			8.0E-04	r		0.1	60238-56-4	Chlorthiophos	4.9E+01	nc	4.9E+02	nc	2.9E+00	nc	2.9E+01	nc		
				4.2E+01	i						Total Chromium (1:6 ratio Cr VI:Cr III)+++	2.1E+02	ca	4.5E+02	ca	1.6E-04	ca			3.8E+01	2.0E+00
		1.5E+00	i							16065-83-1	Chromium III	1.0E+05	max	1.0E+05	max			5.5E+04	nc		
		3.0E-03	i	2.9E+02	i	2.2E-06	i			18540-29-9	Chromium VI+++	3.0E+01	ca**	6.4E+01	ca	2.3E-05	ca	1.1E+02	nc	3.8E+01	2.0E+00
		2.0E-02	p	9.8E+00	p	5.7E-06	p			7440-48-4	Cobalt	9.0E+02	ca**	1.9E+03	ca*	6.9E-04	ca*	7.3E+02	nc		
				2.2E+00	i					8007-45-2	Coke Oven Emissions					3.1E-03	ca				
		4.0E-02	h							7440-50-8	Copper and compounds	3.1E+03	nc	4.1E+04	nc			1.5E+03	nc		
1.9E+00	h			1.9E+00	r			y		123-73-9	Crotonaldehyde	5.3E-03	ca	1.1E-02	ca	3.5E-03	ca	5.9E-03	ca		
		1.0E-01	i			1.1E-01	i	y		98-82-8	Cumene (isopropylbenzene)	5.7E+02	nc	2.0E+03	nc	4.0E+02	nc	6.6E+02	nc		
8.4E-01	h	2.0E-03	h	8.4E-01	r	2.0E-03	r		0.1	21725-46-2	Cyanazine	5.8E-01	ca	2.1E+00	ca	8.0E-03	ca	8.0E-02	ca		
		2.0E-02	i						0.1	57-12-5	Cyanide (free)	1.2E+03	nc	1.2E+04	nc			7.3E+02	nc		
		2.0E-02	i			8.6E-04	i	y		74-90-8	Cyanide (hydrogen)	1.1E+01	nc	3.5E+01	nc	3.1E+00	nc	6.2E+00	nc		
		4.0E-02	i			4.0E-02	r	y		460-19-5	Cyanogen	1.3E+02	nc	4.3E+02	nc	1.5E+02	nc	2.4E+02	nc		
		9.0E-02	i			9.0E-02	r	y		506-68-3	Cyanogen bromide	2.9E+02	nc	9.7E+02	nc	3.3E+02	nc	5.5E+02	nc		
		5.0E-02	i			5.0E-02	r	y		506-77-4	Cyanogen chloride	1.6E+02	nc	5.4E+02	nc	1.8E+02	nc	3.0E+02	nc		
		1.7E+00	r			1.7E+00	i	y		110-82-7	**Cyclohexane**	1.4E+02	sat	1.4E+02	sat	6.2E+03	nc	1.0E+04	nc		
		5.0E+00	i			5.0E+00	r		0.1	108-94-1	Cyclohexanone	1.0E+05	max	1.0E+05	max	1.8E+04	nc	1.8E+05	nc		
		2.0E-01	i			2.0E-01	r		0.1	108-91-8	Cyclohexylamine	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc		
		5.0E-03	i			5.0E-03	r		0.1	68085-85-8	Cyhalothrin/Karate	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		1.0E-02	i			1.0E-02	r		0.1	52315-07-8	Cypermethrin	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		7.5E-03	i			7.5E-03	r		0.1	66215-27-8	Cyromazine	4.6E+02	nc	4.6E+03	nc	2.7E+01	nc	2.7E+02	nc		
		1.0E-02	i			1.0E-02	r		0.1	1861-32-1	Dacthal	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		3.0E-02	i			3.0E-02	r		0.1	75-99-0	Dalapon	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		2.5E-02	i			2.5E-02	r		0.1	39515-41-8	Danitol	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
2.4E-01	i			2.4E-01	r				0.03	72-54-8	DDD	2.4E+00	ca	1.0E+01	ca	2.8E-02	ca	2.8E-01	ca	1.6E+01	8.0E-01
3.4E-01	i			3.4E-01	r				0.03	72-55-9	DDE	1.7E+00	ca	7.0E+00	ca	2.0E-02	ca	2.0E-01	ca	5.4E+01	3.0E+00
3.4E-01	i	5.0E-04	i	3.4E-01	i	5.0E-04	r		0.03	50-29-3	DDT	1.7E+00	ca*	7.0E+00	ca*	2.0E-02	ca*	2.0E-01	ca*	3.2E+01	2.0E+00
		1.0E-02	i			1.0E-02	r		0.1	1163-19-5	Decabromodiphenyl ether	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		4.0E-05	i			4.0E-05	r		0.1	8065-48-3	Demeton	2.4E+00	nc	2.5E+01	nc	1.5E-01	nc	1.5E+00	nc		
6.1E-02	h			6.1E-02	r				0.1	2303-16-4	Diallate	8.0E+00	ca	2.8E+01	ca	1.1E-01	ca	1.1E+00	ca		
		9.0E-04	h			9.0E-04	r		0.1	333-41-5	Diazinon	5.5E+01	nc	5.5E+02	nc	3.3E+00	nc	3.3E+01	nc		
		2.0E-03	n			2.0E-03	r	y		132-64-9	**Dibenzofuran**	1.5E+02	nc	1.6E+03	nc	7.3E+00	nc	1.2E+01	nc		
		1.0E-02	i			1.0E-02	r		0.1	106-37-6	1,4-Dibromobenzene	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
8.4E-02	i	2.0E-02	i	8.4E-02	r	2.0E-02	r	y		124-48-1	Dibromochloromethane	1.1E+00	ca	2.6E+00	ca	8.0E-02	ca	1.3E-01	ca	4.0E-01	2.0E-02
1.4E+00	h	5.7E-05	r	2.4E-03	x	5.7E-05	i	y		96-12-8	**1,2-Dibromo-3-chloropropane (DBCP)**	4.6E-01	ca**	2.0E+00	ca**	2.1E-01	nc	4.8E-02	ca**		
7.0E+00	c			7.0E+00	c			y		96-12-8	**"CAL-Modified PRG"**	3.0E-02	ca	7.6E-02	ca	9.6E-04	ca	1.6E-03	ca		
2.0E+00	i	9.0E-03	i	2.0E+00	i	2.6E-03	i	y		106-93-4	**1,2-Dibromoethane (EDB)**	3.2E-02	ca	7.3E-02	ca	3.4E-03	ca	5.6E-03	ca		
		1.0E-01	i			1.0E-01	r		0.1	84-74-2	Dibutyl phthalate	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc	2.3E+03	2.7E+02
		3.0E-02	i			3.0E-02	r		0.1	1918-00-9	Dicamba	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs)								SOIL SCREENING LEVELS	
												"Direct Contact Exposure Pathways"								"Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		9.0E-02	i			5.7E-02	h	y		95-50-1	**1,2-Dichlorobenzene**	6.0E+02	sat	6.0E+02	sat	2.1E+02	nc	3.7E+02	nc	1.7E+01	9.0E-01
		3.0E-02	n			3.0E-02	r	y		541-73-1	**1,3-Dichlorobenzene**	5.3E+02	nc	6.0E+02	sat	1.1E+02	nc	1.8E+02	nc		
2.4E-02	h	3.0E-02	n	2.2E-02	n	2.3E-01	i	y		106-46-7	1,4-Dichlorobenzene	3.4E+00	ca	7.9E+00	ca	3.1E-01	ca	5.0E-01	ca	2.0E+00	1.0E-01
4.5E-01	i			4.5E-01	r				0.1	91-94-1	3,3-Dichlorobenzidine	1.1E+00	ca	3.8E+00	ca	1.5E-02	ca	1.5E-01	ca	7.0E-03	3.0E-04
		3.0E-02	n			3.0E-02	r		0.1	90-98-2	4,4'-Dichlorobenzophenone	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
9.3E+00	r			9.3E+00	h			y		764-41-0	1,4-Dichloro-2-butene	7.9E-03	ca	1.8E-02	ca	7.2E-04	ca	1.2E-03	ca		
		2.0E-01	i			5.7E-02	h	y		75-71-8	Dichlorodifluoromethane	9.4E+01	nc	3.1E+02	nc	2.1E+02	nc	3.9E+02	nc		
		1.0E-01	h			1.4E-01	h	y		75-34-3	1,1-Dichloroethane	5.1E+02	nc	1.7E+03	nc	5.2E+02	nc	8.1E+02	nc	2.3E+01	1.0E+00
5.7E-03	c			5.7E-03	c			y			"CAL-Modified PRG"	2.8E+00	ca	6.0E+00	ca	1.2E+00	ca	2.0E+00	ca		
9.1E-02	i	2.0E-02	n	9.1E-02	i	1.4E-03	n	y		107-06-2	1,2-Dichloroethane (EDC)	2.8E-01	ca*	6.0E-01	ca*	7.4E-02	ca*	1.2E-01	ca*	2.0E-02	1.0E-03
		5.0E-02	i			5.7E-02	i	y		75-35-4	1,1-Dichloroethylene	1.2E+02	nc	4.1E+02	nc	2.1E+02	nc	3.4E+02	nc	6.0E-02	3.0E-03
		1.0E-02	p			1.0E-02	r	y		156-59-2	1,2-Dichloroethylene (cis)	4.3E+01	nc	1.5E+02	nc	3.7E+01	nc	6.1E+01	nc	4.0E-01	2.0E-02
		2.0E-02	i			2.0E-02	r	y		156-60-5	1,2-Dichloroethylene (trans)	6.9E+01	nc	2.3E+02	nc	7.3E+01	nc	1.2E+02	nc	7.0E-01	3.0E-02
		3.0E-03	i			3.0E-03	r		0.1	120-83-2	2,4-Dichlorophenol	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc	1.0E+00	5.0E-02
		8.0E-03	i			8.0E-03	r		0.1	94-82-6	4-(2,4-Dichlorophenoxy)butyric Acid (2,4-DB)	4.9E+02	nc	4.9E+03	nc	2.9E+01	nc	2.9E+02	nc		
		1.0E-02	i			1.0E-02	r		0.05	94-75-7	2,4-Dichlorophenoxyacetic Acid (2,4-D)	6.9E+02	nc	7.7E+03	nc	3.7E+01	nc	3.6E+02	nc		
6.8E-02	h	1.1E-03	r	6.8E-02	r	1.1E-03	i	y		78-87-5	1,2-Dichloropropane	3.4E-01	ca*	7.4E-01	ca*	9.9E-02	ca*	1.6E-01	ca*	3.0E-02	1.0E-03
		2.0E-02	p			2.0E-02	r	y		142-28-9	**1,3-Dichloropropane**	1.0E+02	nc	3.6E+02	nc	7.3E+01	nc	1.2E+02	nc		
1.0E-01	i	3.0E-02	i	1.4E-02	i	5.7E-03	i	y		542-75-6	1,3-Dichloropropene	7.8E-01	ca	1.8E+00	ca	4.8E-01	ca	4.0E-01	ca	4.0E-03	2.0E-04
		3.0E-03	i			3.0E-03	r		0.1	616-23-9	2,3-Dichloropropanol	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
2.9E-01	i	5.0E-04	i	2.9E-01	r	1.4E-04	i		0.1	62-73-7	Dichlorvos	1.7E+00	ca*	5.9E+00	ca*	2.3E-02	ca*	2.3E-01	ca*		
4.4E-01	x			4.4E-01	r				0.1	115-32-2	Dicofol	1.1E+00	ca	3.9E+00	ca	1.5E-02	ca	1.5E-01	ca		
		3.0E-02	h			5.7E-05	x	y		77-73-6	Dicyclopentadiene	5.4E-01	nc	1.8E+00	nc	2.1E-01	nc	4.2E-01	nc		
1.6E+01	i	5.0E-05	i	1.6E+01	i	5.0E-05	r		0.1	60-57-1	Dieldrin	3.0E-02	ca	1.1E-01	ca	4.2E-04	ca	4.2E-03	ca	4.0E-03	2.0E-04
		1.0E-02	p			5.7E-03	p		0.1	112-34-5	Diethylene glycol, monobutyl ether	6.1E+02	nc	6.2E+03	nc	2.1E+01	nc	3.6E+02	nc		
		6.0E-02	p			8.6E-04	p		0.1	111-90-0	Diethylene glycol, monoethyl ether	3.7E+03	nc	3.7E+04	nc	3.1E+00	nc	2.2E+03	nc		
		4.0E-04	p			4.0E-04	r		0.1	617-84-5	Diethylformamide	2.4E+01	nc	2.5E+02	nc	1.5E+00	nc	1.5E+01	nc		
1.2E-03	i	6.0E-01	i	1.2E-03	r	6.0E-01	r		0.1	103-23-1	Di(2-ethylhexyl)adipate	4.1E+02	ca	1.4E+03	ca	5.6E+00	ca	5.6E+01	ca		
		8.0E-01	i			8.0E-01	r		0.1	84-66-2	Diethyl phthalate	4.9E+04	nc	1.0E+05	max	2.9E+03	nc	2.9E+04	nc		
4.7E+03	h			4.7E+03	r				0.1	56-53-1	Diethylstilbestrol	1.0E-04	ca	3.7E-04	ca	1.4E-06	ca	1.4E-05	ca		
		8.0E-02	i			8.0E-02	r		0.1	43222-48-6	Difenzoquat (Avenge)	4.9E+03	nc	4.9E+04	nc	2.9E+02	nc	2.9E+03	nc		
		2.0E-02	i			2.0E-02	r		0.1	35367-38-5	Diflubenzuron	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		1.1E+01	r			1.1E+01	i	y		75-37-6	1,1-Difluoroethane					4.2E+04	nc	6.9E+04	nc		
		2.0E-02	n			2.0E-02	r		0.1	28553-12-0	Diisononyl phthalate	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
						1.1E-01	p			108-20-3	**Diisopropyl ether**					4.0E+02	nc				
		8.0E-02	i			8.0E-02	r		0.1	1445-75-6	Diisopropyl methylphosphonate	4.9E+03	nc	4.9E+04	nc	2.9E+02	nc	2.9E+03	nc		
		2.0E-02	i			2.0E-02	r		0.1	55290-64-7	Dimethipin	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		2.0E-04	i			2.0E-04	r		0.1	60-51-5	Dimethoate	1.2E+01	nc	1.2E+02	nc	7.3E-01	nc	7.3E+00	nc		
1.4E-02	h			1.4E-02	r				0.1	119-90-4	3,3'-Dimethoxybenzidine	3.5E+01	ca	1.2E+02	ca	4.8E-01	ca	4.8E+00	ca		
		5.7E-06	r			5.7E-06	x	y		124-40-3	Dimethylamine	6.7E-02	nc	2.5E-01	nc	2.1E-02	nc	3.5E-02	nc		
		2.0E-03	i			2.0E-03	r		0.1	121-69-7	N-N-Dimethylaniline	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
7.5E-01	h			7.5E-01	r				0.1	95-68-1	2,4-Dimethylaniline	6.5E-01	ca	2.3E+00	ca	9.0E-03	ca	9.0E-02	ca		

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TOXICITY VALUES										CAS No.	CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils			Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
5 8E-01	h			5.8E-01	r				0.1	21436-96-4	2,4-Dimethylaniline hydrochloride	8.4E-01	ca	3.0E+00	ca	1.2E-02	ca	1.2E-01	ca		
2.3E+00	p			2.3E+00	r				0.1	119-93-7	**3,3'-Dimethylbenzidine**	2.1E-01	ca	7.5E-01	ca	2.9E-03	ca	2.9E-02	ca		
		1.0E-01	h			8.6E-03	i		0.1	68-12-2	N,N-Dimethylformamide	6.1E+03	nc	6.2E+04	nc	3.1E+01	nc	3.6E+03	nc		
		1.0E-03	n			1.0E-03	r		0.1	122-09-8	Dimethylphenethylamine	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		2.0E-02	i			2.0E-02	r		0.1	105-67-9	2,4-Dimethylphenol	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc	9.0E+00	4.0E-01
		6.0E-04	i			6.0E-04	r		0.1	576-26-1	2,6-Dimethylphenol	3.7E+01	nc	3.7E+02	nc	2.2E+00	nc	2.2E+01	nc		
		1.0E-03	i			1.0E-03	r		0.1	95-65-8	3,4-Dimethylphenol	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		1.0E+01	h			1.0E+01	r		0.1	131-11-3	Dimethyl phthalate	1.0E+05	max	1.0E+05	max	3.7E+04	nc	3.6E+05	nc		
		1.0E-01	i			1.0E-01	r		0.1	120-61-6	Dimethyl terephthalate	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		1.0E-04	p			1.0E-04	r		0.1	534-52-1	**4,6-Dinitro-o-cresol**	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		2.0E-03	i			2.0E-03	r		0 1	131-89-5	4,6-Dinitro-o-cyclohexyl phenol	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		1.0E-04	p			1.0E-04	r		0.1	528-29-0	1,2-Dinitrobenzene	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		1.0E-04	i			1.0E-04	r		0.1	99-65-0	1,3-Dinitrobenzene	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		1.0E-04	p			1.0E-04	r		0.1	100-25-4	1,4-Dinitrobenzene	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		2.0E-03	i			2.0E-03	r		0.1	51-28-5	2,4-Dinitrophenol	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc	3.0E-01	1.0E-02
6.8E-01	i			6.8E-01	r				0.1	25321-14-6	Dinitrotoluene mixture	7.2E-01	ca	2.5E+00	ca	9.9E-03	ca	9.9E-02	ca	8.0E-04	4.0E-05
		2.0E-03	i			2.0E-03	r		0.1	121-14-2	2,4-Dinitrotoluene (also see Dinitrotoluene mixture)	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc	8.0E-04	4.0E-05
		1.0E-03	h			1.0E-03	r		0.1	606-20-2	2,6-Dinitrotoluene (also see Dinitrotoluene mixture)	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc	7.0E-04	3.0E-05
		1.0E-03	i			1.0E-03	r		0.1	88-85-7	Dinoseb	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		4.0E-02	p			4.0E-02	r		0.1	117-84-0	di-n-Octyl phthalate	2.4E+03	nc	2.5E+04	nc	1.5E+02	nc	1.5E+03	nc	1.0E+04	1.0E+04
1.1E-02	i			1.1E-02	r				0.1	123-91-1	1,4-Dioxane	4.4E+01	ca	1.6E+02	ca	6.1E-01	ca	6.1E+00	ca		
1.5E+05	h			1.5E+05	h				0.03	1746-01-6	Dioxin (2,3,7,8-TCDD)+++	3.9E-06	ca	1.6E-05	ca	4.5E-08	ca	4.5E-07	ca		
		3.0E-02	i			3.0E-02	r		0.1	957-51-7	Diphenamid	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		2.5E-02	i			2.5E-02	r		0.1	122-39-4	Diphenylamine	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		3.0E-04	p			3.0E-04	r		0.1	74-31-7	N,N-Diphenyl-1,4 benzenediamine (DPPD)	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
8.0E-01	i			8.0E-01	i				0.1	122-66-7	1,2-Diphenylhydrazine	6.1E-01	ca	2.2E+00	ca	8.4E-03	ca	8.4E-02	ca		
		3.0E-03	p			3.0E-03	r		0.1	127-63-9	Diphenyl sulfone	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
		2.2E-03	i			2.2E-03	r		0.1	85-00-7	Diquat	1.3E+02	nc	1.4E+03	nc	8.0E+00	nc	8.0E+01	nc		
8.6E+00	h			8.6E+00	r				0.1	1937-37-7	Direct black 38	5.7E-02	ca	2.0E-01	ca	7.8E-04	ca	7.8E-03	ca		
8.1E+00	h			8.1E+00	r				0.1	2602-46-2	Direct blue 6	6.0E-02	ca	2.1E-01	ca	8.3E-04	ca	8.3E-03	ca		
9 3E+00	h			9.3E+00	r				0.1	16071-86-6	Direct brown 95	5.2E-02	ca	1.9E-01	ca	7.2E-04	ca	7.2E-03	ca		
		4.0E-05	i			4.0E-05	r		0.1	298-04-4	Disulfoton	2.4E+00	nc	2.5E+01	nc	1.5E-01	nc	1.5E+00	nc		
		1.0E-02	i			1.0E-02	r		0.1	505-29-3	1,4-Dithiane	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		2.0E-03	i			2.0E-03	r		0.1	330-54-1	Diuron	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		4.0E-03	i			4.0E-03	r		0.1	2439-10-3	Dodine	2.4E+02	nc	2.5E+03	nc	1.5E+01	nc	1.5E+02	nc		
		1.0E-01	n							7429-91-6	Dysprosium	7.8E+03	nc	1.0E+05	max			3.6E+03	nc		
		6.0E-03	i			6.0E-03	r		0.1	115-29-7	Endosulfan	3.7E+02	nc	3.7E+03	nc	2.2E+01	nc	2.2E+02	nc	1.8E+01	9.0E-01
		2.0E-02	i			2.0E-02	r		0.1	145-73-3	Endothall	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		3.0E-04	i			3.0E-04	r		0.1	72-20-8	Endrin	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc	1.0E+00	5.0E-02
9.9E-03	i	2.0E-03	h	4.2E-03	h	2.9E-04	i	y		106-89-8	Epichlorohydrin	7.6E+00	nc	2.6E+01	nc	1.0E+00	nc	2.0E+00	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
8.00E-02	r			8.00E-02	c			y			**"CAL-Modified PRG"**	1.3E+00	nc	2.9E+00	nc	8.4E-02	nc	1.4E-01	nc		
		5.7E-03	r			5.7E-03	i		0.1	106-88-7	1,2-Epoxybutane	3.5E+02	nc	3.5E+03	nc	2.1E+01	nc	2.1E+02	nc		
		2.5E-02	i			2.5E-02	r		0.1	759-94-4	EPTC (S-Ethyl dipropylthiocarbamate)	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		5.0E-03	i			5.0E-03	r		0.1	16672-87-0	Ethephon (2-chloroethyl phosphonic acid)	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		5.0E-04	i			5.0E-04	r		0.1	563-12-2	Ethion	3.1E+01	nc	3.1E+02	nc	1.8E+00	nc	1.8E+01	nc		
		4.0E-01	h			5.7E-02	i		0.1	110-80-5	2-Ethoxyethanol	2.4E+04	nc	1.0E+05	max	2.1E+02	nc	1.5E+04	nc		
		3.0E-01	h			3.0E-01	r		0.1	111-15-9	2-Ethoxyethanol acetate	1.8E+04	nc	1.0E+05	max	1.1E+03	nc	1.1E+04	nc		
		9.0E-01	i			9.0E-01	r	y		141-78-6	Ethyl acetate	1.9E+04	nc	3.7E+04	sat	3.3E+03	nc	5.5E+03	nc		
4.8E-02	h			4.8E-02	r			y		140-88-5	Ethyl acrylate	2.1E-01	ca	4.5E-01	ca	1.4E-01	ca	2.3E-01	ca		
		1.0E-01	i			2.9E-01	i	y		100-41-4	**Ethylbenzene**	4.0E+02	sat	4.0E+02	sat	1.1E+03	nc	1.3E+03	nc	1.3E+01	7.0E-01
2.9E-03	n	4.0E-01	n	2.9E-03	r	2.9E+00	i	y		75-00-3	Ethyl chloride	3.0E+00	ca	6.5E+00	ca	2.3E+00	ca	4.6E+00	ca		
		3.0E-01	h			3.0E-01	r		0.1	109-78-4	Ethylene cyanohydrin	1.8E+04	nc	1.0E+05	max	1.1E+03	nc	1.1E+04	nc		
		9.0E-02	p			9.0E-02	r		0.1	107-15-3	**Ethylene diamine**	5.5E+03	nc	5.5E+04	nc	3.3E+02	nc	3.3E+03	nc		
		2.0E+00	i			2.0E+00	r		0.1	107-21-1	Ethylene glycol	1.0E+05	max	1.0E+05	max	7.3E+03	nc	7.3E+04	nc		
		5.0E-01	i			3.7E+00	i		0.1	111-76-2	Ethylene glycol, monobutyl ether	3.1E+04	nc	1.0E+05	max	1.4E+04	nc	1.8E+04	nc		
1.0E+00	h			3.5E-01	h			y		75-21-8	Ethylene oxide	1.4E-01	ca	3.4E-01	ca	1.9E-02	ca	2.4E-02	ca		
1.1E-01	h	8.0E-05	i	1.1E-01	r	8.0E-05	r		0.1	96-45-7	Ethylene thiourea (ETU)	4.4E+00	ca**	1.6E+01	ca**	6.1E-02	ca**	6.1E-01	ca**		
		2.0E-01	i			2.0E-01	r	y		60-29-7	Ethyl ether	1.8E+03	sat	1.8E+03	sat	7.3E+02	nc	1.2E+03	nc		
		9.0E-02	h			9.0E-02	r	y		97-63-2	Ethyl methacrylate	1.4E+02	sat	1.4E+02	sat	3.3E+02	nc	5.5E+02	nc		
		1.0E-05	i			1.0E-05	r		0.1	2104-64-5	Ethyl p-nitrophenyl phenylphosphorothioate	6.1E-01	nc	6.2E+00	nc	3.7E-02	nc	3.6E-01	nc		
		3.0E+00	i			3.0E+00	r		0.1	84-72-0	Ethylphthalyl ethyl glycolate	1.0E+05	max	1.0E+05	max	1.1E+04	nc	1.1E+05	nc		
		8.0E-03	i			8.0E-03	r		0.1	101200-48-0	Express	4.9E+02	nc	4.9E+03	nc	2.9E+01	nc	2.9E+02	nc		
		2.5E-04	i			2.5E-04	r		0.1	22224-92-6	Fenamiphos	1.5E+01	nc	1.5E+02	nc	9.1E-01	nc	9.1E+00	nc		
		1.3E-02	i			1.3E-02	r		0.1	2164-17-2	Fluometuron	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		6.0E-02	i						0.1	16984-48-8	Fluorine (soluble fluoride)	3.7E+03	nc	3.7E+04	nc			2.2E+03	nc		
		8.0E-02	i			8.0E-02	r		0.1	59756-60-4	Fluoridone	4.9E+03	nc	4.9E+04	nc	2.9E+02	nc	2.9E+03	nc		
		2.0E-02	i			2.0E-02	r		0.1	56425-91-3	Flurprimidol	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		6.0E-02	i			6.0E-02	r		0.1	66332-96-5	Flutolanil	3.7E+03	nc	3.7E+04	nc	2.2E+02	nc	2.2E+03	nc		
		1.0E-02	i			1.0E-02	r		0.1	69409-94-5	Fluvalinate	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
3.5E-03	i	1.0E-01	i	3.5E-03	r	1.0E-01	r		0.1	133-07-3	Folpet	1.4E+02	ca*	4.9E+02	ca	1.9E+00	ca	1.9E+01	ca		
1.9E-01	i			1.9E-01	r				0.1	72178-02-0	Fomesafen	2.6E+00	ca	9.1E+00	ca	3.5E-02	ca	3.5E-01	ca		
		2.0E-03	i			2.0E-03	r		0.1	944-22-9	Fonofos	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		1.5E-01	i	4.6E-02	i				0.1	50-00-0	Formaldehyde	9.2E+03	nc	1.0E+05	nc	1.5E-01	ca	5.5E+03	nc		
		2.0E+00	h			8.6E-04	p		0.1	64-18-6	**Formic Acid**	1.0E+05	max	1.0E+05	max	3.1E+00	nc	7.3E+04	nc		
		3.0E+00	i			3.0E+00	r		0.1	39148-24-8	Fosetyl-al	1.0E+05	max	1.0E+05	max	1.1E+04	nc	1.1E+05	nc		
		3.0E+01	i			8.6E+00	h	y		76-13-1	Freon 113	5.6E+03	sat	5.6E+03	sat	3.1E+04	nc	5.9E+04	nc		
		1.0E-03	i			1.0E-03	r	y		110-00-9	Furan	2.5E+00	nc	8.5E+00	nc	3.7E+00	nc	6.1E+00	nc		
3.8E+00	h			3.8E+00	r				0.1	67-45-8	Furazolidone	1.3E-01	ca	4.5E-01	ca	1.8E-03	ca	1.8E-02	ca		
		3.0E-03	i			1.4E-02	h		0.1	98-01-1	Furfural	1.8E+02	nc	1.8E+03	nc	5.2E+01	nc	1.1E+02	nc		
5.0E+01	h			5.0E+01	r				0.1	531-82-8	Furium	9.7E-03	ca	3.4E-02	ca	1.3E-04	ca	1.3E-03	ca		
3.0E-02	i			3.0E-02	r				0.1	60568-05-0	Furmecyclox	1.6E+01	ca	5.7E+01	ca	2.2E-01	ca	2.2E+00	ca		
		4.0E-04	i			4.0E-04	r		0.1	77182-82-2	Glufosinate-ammonium	2.4E+01	nc	2.5E+02	nc	1.5E+00	nc	1.5E+01	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		4.0E-04	i			2.9E-04	h		0.1	765-34-4	Glycidaldehyde	2.4E+01	nc	2.5E+02	nc	1.0E+00	nc	1.5E+01	nc		
		1.0E-01	i			1.0E-01	r		0.1	1071-83-6	Glyphosate	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		5.0E-05	i			5.0E-05	r		0.1	69806-40-2	Haloxyfop-methyl	3.1E+00	nc	3.1E+01	nc	1.8E-01	nc	1.8E+00	nc		
		1.3E-02	i			1.3E-02	r		0.1	79277-27-3	Harmony	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
4.5E+00	i	5.0E-04	i	4.6E+00	i	5.0E-04	r		0.1	76-44-8	Heptachlor	1.1E-01	ca	3.8E-01	ca	1.5E-03	ca	1.5E-02	ca	2.3E+01	1.0E+00
9.1E+00	i	1.3E-05	i	9.1E+00	i	1.3E-05	r		0.1	1024-57-3	Heptachlor epoxide	5.3E-02	ca*	1.9E-01	ca*	7.4E-04	ca*	7.4E-03	ca*	7.0E-01	3.0E-02
		2.0E-03	i			2.0E-03	r		0.1	87-82-1	Hexabromobenzene	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
1.6E+00	i	8.0E-04	i	1.6E+00	i	8.0E-04	r		0.1	118-74-1	Hexachlorobenzene	3.0E-01	ca	1.1E+00	ca	4.2E-03	ca	4.2E-02	ca	2.0E+00	1.0E-01
7.8E-02	i	3.0E-04	n	7.8E-02	i	3.0E-04	r		0.1	87-68-3	Hexachlorobutadiene	6.2E+00	ca**	2.2E+01	ca**	8.6E-02	ca*	8.6E-01	ca*	2.0E+00	1.0E-01
6.3E+00	i	5.0E-04	n	6.3E+00	i	5.0E-04	r		0.04	319-84-6	HCH (alpha) BHC	9.0E-02	ca	3.6E-01	ca	1.1E-03	ca	1.1E-02	ca	5.0E-04	3.0E-05
1.8E+00	i	2.0E-04	n	1.8E+00	i	2.0E-04	r		0.04	319-85-7	HCH (beta) BHC	3.2E-01	ca	1.3E+00	ca	3.7E-03	ca	3.7E-02	ca	3.0E-03	1.0E-04
1.3E+00	h	3.0E-04	i	1.3E+00	r	3.0E-04	r		0.04	58-89-9	HCH (gamma) Lindane	4.4E-01	ca*	1.7E+00	ca	5.2E-03	ca	5.2E-02	ca	9.0E-03	5.0E-04
1.8E+00	i			1.8E+00	i				0.04	608-73-1	HCH-technical	3.2E-01	ca	1.3E+00	ca	3.8E-03	ca	3.7E-02	ca	3.0E-03	1.0E-04
		6.0E-03	i			5.7E-05	i		0.1	77-47-4	Hexachlorocyclopentadiene	3.7E+02	nc	3.7E+03	nc	2.1E-01	nc	2.2E+02	nc	4.0E+02	2.0E+01
1.4E-02	i	1.0E-03	i	1.4E-02	i	1.0E-03	r		0.1	67-72-1	Hexachloroethane	3.5E+01	ca**	1.2E+02	ca**	4.8E-01	ca**	4.8E+00	ca**	5.0E-01	2.0E-02
		3.0E-04	i			3.0E-04	r		0.1	70-30-4	Hexachlorophene	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
1.1E-01	i	3.0E-03	i	1.1E-01	r	3.0E-03	r		0.1	121-82-4	Hexahydro-1,3,5-trinitro-1,3,5-triazine	4.4E+00	ca*	1.6E+01	ca	6.1E-02	ca	6.1E-01	ca		
		2.9E-06	r			2.9E-06	i		0.1	822-06-0	1,6-Hexamethylene diisocyanate	1.7E-01	nc	1.8E+00	nc	1.0E-02	nc	1.0E-01	nc		
		1.1E+01	p			5.7E-02	i	y		110-54-3	**n-Hexane**	1.1E+02	sat	1.1E+02	sat	2.1E+02	nc	4.2E+02	nc		
		3.3E-02	i			3.3E-02	r		0.1	51235-04-2	Hexazinone	2.0E+03	nc	2.0E+04	nc	1.2E+02	nc	1.2E+03	nc		
		5.0E-02	i			5.0E-02	r		0.1	2691-41-0	HMX	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
3.0E+00	i			1.7E+01	i				0.1	302-01-2	Hydrazine, hydrazine sulfate	1.6E-01	ca	5.7E-01	ca	3.9E-04	ca	2.2E-02	ca		
3.0E+00	n			1.7E+01	n				0.1	60-34-4	Hydrazine, monomethyl	1.6E-01	ca	5.7E-01	ca	4.0E-04	ca	2.2E-02	ca		
3.0E+00	n			1.7E+01	n				0.1	57-14-7	Hydrazine, dimethyl	1.6E-01	ca	5.7E-01	ca	4.0E-04	ca	2.2E-02	ca		
						5.7E-03	i			7647-01-0	Hydrogen chloride					2.1E+01	nc				
		2.0E-02	i			8.6E-04	i	y		74-90-8	Hydrogen cyanide	1.1E+01	nc	3.5E+01	nc	3.1E+00	nc	6.2E+00	nc		
		3.0E-03	i			2.9E-04	i			7783-06-4	Hydrogen sulfide					1.0E+00	nc	1.1E+02	nc		
5.6E-02	p	4.0E-02	p	5.6E-02	r	4.0E-02	r		0.1	123-31-9	**p-Hydroquinone**	8.7E+00	ca	3.1E+01	ca	1.2E-01	ca	1.2E+00	ca		
		1.3E-02	i			1.3E-02	r		0.1	35554-44-0	Imazalil	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		2.5E-01	i			2.5E-01	r		0.1	81335-37-7	Imazaquin	1.5E+04	nc	1.0E+05	max	9.1E+02	nc	9.1E+03	nc		
		4.0E-02	i			4.0E-02	r		0.1	36734-19-7	Iprodione	2.4E+03	nc	2.5E+04	nc	1.5E+02	nc	1.5E+03	nc		
		3.0E-01	n							7439-89-6	Iron	2.3E+04	nc	1.0E+05	max			1.1E+04	nc		
		3.0E-01	i			3.0E-01	r	y		78-83-1	Isobutanol	1.3E+04	nc	4.0E+04	sat	1.1E+03	nc	1.8E+03	nc		
9.5E-04	i	2.0E-01	i	9.5E-04	r	2.0E-01	r		0.1	78-59-1	Isophorone	5.1E+02	ca*	5.1E+02	ca*	7.1E+00	ca	7.1E+01	ca	5.0E-01	3.0E-02
		1.5E-02	i			1.5E-02	r		0.1	33820-53-0	Isopropalin	9.2E+02	nc	9.2E+03	nc	5.5E+01	nc	5.5E+02	nc		
		1.0E-01	i			1.1E-01	r		0.1	1832-54-8	Isopropyl methyl phosphonic acid	6.1E+03	nc	6.2E+04	nc	4.0E+02	nc	3.6E+03	nc		
		5.0E-02	i			5.0E-02	r		0.1	82558-50-7	Isoxaben	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
8.0E+00	p	2.0E-04	p	8.0E+00	r	2.0E-04	r		0.1	143-50-0	Kepone	6.1E-02	ca	2.2E-01	ca	8.4E-04	ca	8.4E-03	ca		
		2.0E-03	i			2.0E-03	r		0.1	77501-63-4	Lactofen	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
www.epa.gov/superfund/programs/lead/ieubk.htm										7439-92-1	**Lead+++**	4.0E+02	nc	8.0E+02	nc						
www.dtsc.ca.gov/ScienceTechnology/ledspred.html											"CAL-Modified PRG"+++	1.5E+02	nc								
		1.0E-07	i						0.1	78-00-2	Lead (tetraethyl)	6.1E-03	nc	6.2E-02	nc			3.6E-03	nc		

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ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		2.0E-03	i			2.0E-03	r		0.1	330-55-2	Linuron	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		2.0E-02	x							7439-93-2	Lithium	1.6E+03	nc	2.0E+04	nc			7.3E+02	nc		
		2 0E-01	i			2.0E-01	r		0.1	83055-99-6	Londax	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc		
		2.0E-02	i			2.0E-02	r		0.1	121-75-5	Malathion	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		1.0E-01	i			1.0E-01	r		0.1	108-31-6	Maleic anhydride	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		5.0E-01	i			5.0E-01	r	y		123-33-1	Maleic hydrazide	1.7E+03	nc	2.4E+03	sat	1.8E+03	nc	3.0E+03	nc		
		1.0E-04	p			1.0E-04	r		0.1	109-77-3	**Malononitrile**	6.1E+00	nc	6.2E+01	nc	3.7E-01	nc	3.6E+00	nc		
		3.0E-02	h			3.0E-02	r		0.1	8018-01-7	Mancozeb	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
6.0E-02	o	5.0E-03	i	6.0E-02	r	5.0E-03	r		0.1	12427-38-2	Maneb	8.1E+00	ca*	2.9E+01	ca	1.1E-01	ca	1.1E+00	ca		
		2.4E-02	i			1.4E-05	i			7439-96-5	Manganese and compounds+++	1.8E+03	nc	1.9E+04	nc	5.1E-02	nc	8.8E+02	nc		
		9.0E-05	h			9.0E-05	r		0.1	950-10-7	Mephosfolan	5.5E+00	nc	5.5E+01	nc	3.3E-01	nc	3.3E+00	nc		
		3.0E-02	i			3.0E-02	r		0.1	24307-26-4	Mepiquat chloride	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
2.9E-02	n	1.0E-01	n	2.9E-02	r	1 0E-01	r		0.1	149-30-4	2-Mercaptobenzothiazole	1.7E+01	ca	5.9E+01	ca	2.3E-01	ca	2.3E+00	ca		
		3.0E-04	i							7487-94-7	Mercury and compounds	2.3E+01	nc	3.1E+02	nc			1.1E+01	nc		
						8.6E-05	i			7439-97-6	Mercury (elemental)					3.1E-01	nc				
		1.0E-04	i						0.1	22967-92-6	Mercury (methyl)	6.1E+00	nc	6.2E+01	nc			3.6E+00	nc		
		3.0E-05	i			3.0E-05	r		0.1	150-50-5	Merphos	1.8E+00	nc	1.8E+01	nc	1.1E-01	nc	1.1E+00	nc		
		3.0E-05	i			3.0E-05	r		0.1	78-48-8	Merphos oxide	1.8E+00	nc	1.8E+01	nc	1.1E-01	nc	1.1E+00	nc		
		6.0E-02	i			6.0E-02	r		0.1	57837-19-1	Metalaxyl	3.7E+03	nc	3.7E+04	nc	2.2E+02	nc	2.2E+03	nc		
		1.0E-04	i			2.0E-04	h	y		126-98-7	Methacrylonitrile	2.1E+00	nc	8.4E+00	nc	7.3E-01	nc	1.0E+00	nc		
		5.0E-05	i			5.0E-05	r		0.1	10265-92-6	Methamidophos	3.1E+00	nc	3.1E+01	nc	1.8E-01	nc	1.8E+00	nc		
		5.0E-01	i			5.0E-01	r		0.1	67-56-1	Methanol	3.1E+04	nc	1.0E+05	max	1.8E+03	nc	1.8E+04	nc		
		1.0E-03	i			1.0E-03	r		0.1	950-37-8	Methidathion	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		2.5E-02	i			2.5E-02	r	y		16752-77-5	Methomyl	4.4E+01	nc	1.5E+02	nc	9.1E+01	nc	1.5E+02	nc		
		5.0E-03	i			5.0E-03	r		0.1	72-43-5	Methoxychlor	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc	1.6E+02	8.0E+00
		1.0E-03	h			5.7E-03	i		0.1	109-86-4	2-Methoxyethanol	6.1E+01	nc	6.2E+02	nc	2.1E+01	nc	3.6E+01	nc		
		2.0E-03	h			2.0E-03	r		0.1	110-49-6	2-Methoxyethanol acetate	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
4.6E-02	h			4.6E-02	r				0.1	99-59-2	2-Methoxy-5-nitroaniline	1.1E+01	ca	3.7E+01	ca	1.5E-01	ca	1.5E+00	ca		
		1.0E+00	h			1.0E+00	r	y		79-20-9	Methyl acetate	2.2E+04	nc	9.2E+04	nc	3.7E+03	nc	6.1E+03	nc		
		3.0E-02	h			3.0E-02	r	y		96-33-3	Methyl acrylate	7.0E+01	nc	2.3E+02	nc	1.1E+02	nc	1.8E+02	nc		
2.4E-01	h			2.4E-01	r				0.1	95-53-4	2-Methylaniline (o-toluidine)	2.0E+00	ca	7.2E+00	ca	2.8E-02	ca	2.8E-01	ca		
1.8E-01	h			1.8E-01	r				0.1	636-21-5	2-Methylaniline hydrochloride	2.7E+00	ca	9.6E+00	ca	3.7E-02	ca	3.7E-01	ca		
		5.0E-04	i			5.0E-04	r		0.1	94-74-6	2-Methyl-4-chlorophenoxyacetic acid	3.1E+01	nc	3.1E+02	nc	1.8E+00	nc	1.8E+01	nc		
		1.0E-02	i			1.0E-02	r		0.1	94-81-5	4-(2-Methyl-4-chlorophenoxy) butyric acid	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		1.0E-03	i			1.0E-03	r		0.1	93-65-2	2-(2-Methyl-4-chlorophenoxy) propionic acid	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		1.0E-03	i			1.0E-03	r		0.1	16484-77-8	2-(2-Methyl-1,4-chlorophenoxy) propionic acid	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		8.6E-01	r			8.6E-01	h	y		108-87-2	Methylcyclohexane	2.6E+03	nc	8.7E+03	nc	3.1E+03	nc	5.2E+03	nc		
2 5E-01	h			2.5E-01	r				0.1	101-77-9	4,4'-Methylenebisbenzeneamine	1.9E+00	ca	6.9E+00	ca	2.7E-02	ca	2.7E-01	ca		
1.3E-01	h	7.0E-04	h	1.3E-01	h	7.0E-04	r		0.1	101-14-4	4,4'-Methylene bis(2-chloroaniline)	3.7E+00	ca*	1.3E+01	ca*	5.2E-02	ca*	5.2E-01	ca*		
4.6E-02	i			4.6E-02	r				0.1	101-61-1	4,4'-Methylene bis(N,N'-dimethyl)aniline	1.1E+01	ca	3.7E+01	ca	1.5E-01	ca	1.5E+00	ca		
		1.0E-02	h			1.0E-02	r	y		74-95-3	Methylene bromide	6.7E+01	nc	2.3E+02	nc	3.7E+01	nc	6.1E+01	nc		
7.5E-03	i	6.0E-02	i	1.6E-03	i	8.6E-01	h	y		75-09-2	Methylene chloride	9.1E+00	ca	2.1E+01	ca	4.1E+00	ca	4.3E+00	ca	2.0E-02	1.0E-03

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		1.7E-04	r			1.7E-04	i		0.1	101-68-8	4,4'-Methylene diphenyl diisocyanate	1.0E+01	nc	1.0E+02	nc	6.2E-01	nc	6.2E+00	nc		
		6.0E-01	i			1.4E+00	i	y		78-93-3	**Methyl ethyl ketone (2-Butanone)**	2.2E+04	nc	1.1E+05	nc	5.1E+03	nc	7.0E+03	nc		
		8.0E-02	h			8.6E-01	i	y		108-10-1	**Methyl isobutyl ketone**	5.3E+03	nc	4.7E+04	nc	3.1E+03	nc	2.0E+03	nc		
		5.7E-04	r			5.7E-04	n		0.1	74-93-1	Methyl Mercaptan	3.5E+01	nc	3.5E+02	nc	2.1E+00	nc	2.1E+01	nc		
		1.4E+00	i			2.0E-01	i	y		80-62-6	Methyl methacrylate	2.2E+03	nc	2.7E+03	sat	7.3E+02	nc	1.4E+03	nc		
3.3E-02	h			3.3E-02	r				0.1	99-55-8	2-Methyl-5-nitroaniline	1.5E+01	ca	5.2E+01	ca	2.0E-01	ca	2.0E+00	ca		
		2.5E-04	i			2.5E-04	r		0.1	298-00-0	Methyl parathion	1.5E+01	nc	1.5E+02	nc	9.1E-01	nc	9.1E+00	nc		
		5.0E-02	i			5.0E-02	r		0.1	95-48-7	2-Methylphenol	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc	1.5E+01	8.0E-01
		5.0E-02	i			5.0E-02	r		0.1	108-39-4	3-Methylphenol	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		5.0E-03	h			5.0E-03	r		0.1	106-44-5	4-Methylphenol	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.0E-02	p			2.0E-02	r		0.1	993-13-5	Methyl phosphonic acid	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		6.0E-03	h			1.1E-02	h	y		25013-15-4	Methyl styrene (mixture)	1.3E+02	nc	5.4E+02	nc	4.2E+01	nc	6.0E+01	nc		
		7.0E-02	h			7.0E-02	r	y		98-83-9	Methyl styrene (alpha)	6.8E+02	sat	6.8E+02	sat	2.6E+02	nc	4.3E+02	nc		
1.8E-03	c	8.6E-01	r	9.1E-04	c	8.6E-01	i	y		1634-04-4	**Methyl tertbutyl ether (MTBE)**	3.2E+01	ca	7.0E+01	ca	7.4E+00	ca	1.1E+01	ca		
		1.5E-01	i			1.5E-01	r		0.1	51218-45-2	Metolaclor (Dual)	9.2E+03	nc	9.2E+04	nc	5.5E+02	nc	5.5E+03	nc		
		2.5E-02	i			2.5E-02	r		0.1	21087-64-9	Metribuzin	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
1.8E+00	x	2.0E-04	i	1.8E+00	r	2.0E-04	r		0.1	2385-85-5	Mirex	2.7E-01	ca*	9.6E-01	ca	3.7E-03	ca	3.7E-02	ca		
		2.0E-03	i			2.0E-03	r		0.1	2212-67-1	Molinate	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		5.0E-03	i							7439-98-7	Molybdenum	3.9E+02	nc	5.1E+03	nc			1.8E+02	nc		
		1.0E-01	i			1.0E-01	r		0.1	10599-90-3	Monochloramine	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		2.0E-03	i			2.0E-03	r		0.1	300-76-5	Naled	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		1.0E-01	i			1.0E-01	r		0.1	15299-99-7	Napropamide	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
		2.0E-02	i							7440-02-0	Nickel (soluble salts)	1.6E+03	nc	2.0E+04	nc			7.3E+02	nc	1.3E+02	7.0E+00
				8.4E-01	i						Nickel refinery dust					8.0E-03	ca				
				1.7E+00	i					12035-72-2	Nickel subsulfide			1.1E+04	ca	4.0E-03	ca				
Tap Water PRG Based on Infant NOAEL (see IRIS)										14797-55-8	Nitrate+++							1.0E+04	nc		
Tap Water PRG Based on Infant NOAEL (see IRIS)										14797-65-0	Nitrite+++							1.0E+03	nc		
		3.0E-03	p			3.0E-05	p		0.1	88-74-4	**2-Nitroaniline**	1.8E+02	nc	1.8E+03	nc	1.1E-01	nc	1.1E+02	nc		
2.1E-02	p	3.0E-04	p	2.1E-02	r	3.0E-04	p		0.1	99-09-2	**3-Nitroaniline**	1.8E+01	nc	8.2E+01	ca**	3.2E-01	ca**	3.2E+00	ca**		
2.1E-02	p	3.0E-03	p	2.1E-02	r	1.0E-03	p		0.1	100-01-6	**4-Nitroaniline**	2.3E+01	ca**	8.2E+01	ca*	3.2E-01	ca*	3.2E+00	ca*		
		5.0E-04	i			5.7E-04	h	y		98-95-3	Nitrobenzene	2.0E+01	nc	1.0E+02	nc	2.1E+00	nc	3.4E+00	nc	1.0E-01	7.0E-03
		7.0E-02	h			7.0E-02	r		0.1	67-20-9	Nitrofurantoin	4.3E+03	nc	4.3E+04	nc	2.6E+02	nc	2.6E+03	nc		
1.5E+00	h			1.5E+00	r				0.1	59-87-0	Nitrofurazone	3.2E-01	ca	1.1E+00	ca	4.5E-03	ca	4.5E-02	ca		
1.4E-02	n			1.4E-02	r				0.1	55-63-0	Nitroglycerin	3.5E+01	ca	1.2E+02	ca	4.8E-01	ca	4.8E+00	ca		
		1.0E-01	i			1.0E-01	r		0.1	556-88-7	Nitroguanidine	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc		
9.4E+00	r	5.7E-03	r	9.4E+00	h	5.7E-03	i	y		79-46-9	2-Nitropropane					7.2E-04	ca	1.2E-03	ca		
5.4E+00	i			5.6E+00	i			y		924-16-3	N-Nitrosodi-n-butylamine	2.4E-02	ca	5.8E-02	ca	1.2E-03	ca	2.0E-03	ca		
2.8E+00	i			2.8E+00	r				0.1	1116-54-7	N-Nitrosodiethanolamine	1.7E-01	ca	6.2E-01	ca	2.4E-03	ca	2.4E-02	ca		
1.5E+02	i			1.5E+02	i				0.1	55-18-5	N-Nitrosodiethylamine	3.2E-03	ca	1.1E-02	ca	4.5E-05	ca	4.5E-04	ca		
5.1E+01	i	8.0E-06	p	4.9E+01	i	8.0E-06	r		0.1	62-75-9	**N-Nitrosodimethylamine**	9.5E-03	ca*	3.4E-02	ca	1.4E-04	ca	1.3E-03	ca		
4.9E-03	i	2.0E-02	p	4.9E-03	r	2.0E-02	r		0.1	86-30-6	**N-Nitrosodiphenylamine**	9.9E+01	ca*	3.5E+02	ca*	1.4E+00	ca*	1.4E+01	ca*	1.0E+00	6.0E-02
7.0E+00	i			7.0E+00	r				0.1	621-64-7	N-Nitroso di-n-propylamine	6.9E-02	ca	2.5E-01	ca	9.6E-04	ca	9.6E-03	ca	5.0E-05	2.0E-06

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
2.2E+01	i			2.2E+01	r				0.1	10595-95-6	N-Nitroso-N-methylethylamine	2.2E-02	ca	7.8E-02	ca	3.1E-04	ca	3.1E-03	ca		
2.1E+00	i			2.1E+00	i				0.1	930-55-2	N-Nitrosopyrrolidine	2.3E-01	ca	8.2E-01	ca	3.1E-03	ca	3.2E-02	ca		
		2 0E-02	p			2.0E-02	r	y		99-08-1	**m-Nitrotoluene**	7.3E+02	nc	1.0E+03	sat	7.3E+01	nc	1.2E+02	nc		
2.3E-01	p	1.0E-02	h	2.3E-01	r	1.0E-02	r	y		88-72-2	**o-Nitrotoluene**	8.8E-01	ca	2.2E+00	ca	2.9E-02	ca	4.9E-02	ca		
1.7E-02	p	1.0E-02	p	1.7E-02	r	1.0E-02	r	y		99-99-0	**p-Nitrotoluene**	1.2E+01	ca*	3.0E+01	ca*	4.0E-01	ca*	6.6E-01	ca*		
		4.0E-02	i			4.0E-02	r		0.1	27314-13-2	Norflurazon	2.4E+03	nc	2.5E+04	nc	1.5E+02	nc	1.5E+03	nc		
		7.0E-04	i			7.0E-04	r		0.1	85509-19-9	NuStar	4.3E+01	nc	4.3E+02	nc	2.6E+00	nc	2.6E+01	nc		
		3.0E-03	i			3.0E-03	r		0.1	32536-52-0	Octabromodiphenyl ether	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
		2.0E-03	h			2.0E-03	r		0.1	152-16-9	Octamethylpyrophosphoramide	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		5.0E-02	i			5.0E-02	r		0.1	19044-88-3	Oryzalin	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		5.0E-03	i			5.0E-03	r		0.1	19666-30-9	Oxadiazon	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.5E-02	i			2.5E-02	r		0.1	23135-22-0	Oxamyl	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		3.0E-03	i			3.0E-03	r		0.1	42874-03-3	Oxyfluorfen	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
		1.3E-02	i			1.3E-02	r		0.1	76738-62-0	Paclobutrazol	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		4.5E-03	i			4.5E-03	r		0.1	4685-14-7	Paraquat	2.7E+02	nc	2.8E+03	nc	1.6E+01	nc	1.6E+02	nc		
		6.0E-03	h			6.0E-03	r		0.1	56-38-2	Parathion	3.7E+02	nc	3.7E+03	nc	2.2E+01	nc	2.2E+02	nc		
		5.0E-02	h			5.0E-02	r		0.1	1114-71-2	Pebulate	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		4.0E-02	i			4.0E-02	r		0.1	40487-42-1	Pendimethalin	2.4E+03	nc	2.5E+04	nc	1.5E+02	nc	1.5E+03	nc		
2.3E-02	h			2.3E-02	r				0.1	87-84-3	Pentabromo-6-chloro cyclohexane	2.1E+01	ca	7.5E+01	ca	2.9E-01	ca	2.9E+00	ca		
		2.0E-03	i			2.0E-03	r		0.1	32534-81-9	Pentabromodiphenyl ether	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		8.0E-04	i			8.0E-04	r		0.1	608-93-5	Pentachlorobenzene	4.9E+01	nc	4.9E+02	nc	2.9E+00	nc	2.9E+01	nc		
2 6E-01	h	3.0E-03	i	2.6E-01	r	3.0E-03	r		0.1	82-68-8	Pentachloronitrobenzene	1.9E+00	ca*	6.6E+00	ca	2.6E-02	ca	2.6E-01	ca		
1.2E-01	i	3.0E-02	i	1.2E-01	r	3.0E-02	r		0.25	87-86-5	Pentachlorophenol	3.0E+00	ca	9.0E+00	ca	5.6E-02	ca	5.6E-01	ca	3.0E-02	1.0E-03
		1.0E-04	n							7601-90-3	Perchlorate	7.8E+00	ca/nc	1.0E+02	ca/nc			3.6E+00	ca/nc		
		5.0E-02	i			5.0E-02	r		0 1	52645-53-1	Permethrin	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		2.5E-01	i			2.5E-01	r		0.1	13684-63-4	Phenmedipham	1.5E+04	nc	1.0E+05	max	9.1E+02	nc	9.1E+03	nc		
		3.0E-01	i			3.0E-01	r		0.1	108-95-2	**Phenol**	1.8E+04	nc	1.0E+05	max	1.1E+03	nc	1.1E+04	nc	1.0E+02	5.0E+00
		2.0E-03	n			2.0E-03	r		0.1	92-84-2	Phenothiazine	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		6.0E-03	i			6.0E-03	r		0.1	108-45-2	m-Phenylenediamine	3.7E+02	nc	3.7E+03	nc	2.2E+01	nc	2.2E+02	nc		
4.7E-02	h			4.7E-02	r				0.1	95-54-5	**o-Phenylenediamine**	1.0E+01	ca	3.7E+01	ca	1.4E-01	ca	1.4E+00	ca		
		1.9E-01	h			1.9E-01	r		0.1	106-50-3	p-Phenylenediamine	1.2E+04	nc	1.0E+05	max	6.9E+02	nc	6.9E+03	nc		
		8.0E-05	i			8.0E-05	r		0.1	62-38-4	Phenylmercuric acetate	4.9E+00	nc	4.9E+01	nc	2.9E-01	nc	2.9E+00	nc		
1.9E-03	h			1.9E-03	r				0.1	90-43-7	2-Phenylphenol	2.5E+02	ca	8.9E+02	ca	3.5E+00	ca	3.5E+01	ca		
		2.0E-04	h			2.0E-04	r		0.1	298-02-2	Phorate	1.2E+01	nc	1.2E+02	nc	7.3E-01	nc	7.3E+00	nc		
		2.0E-02	i			2.0E-02	r		0.1	732-11-6	Phosmet	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		3.0E-04	i			8.6E-05	i		0.1	7803-51-2	Phosphine	1.8E+01	nc	1.8E+02	nc	3.1E-01	nc	1.1E+01	nc		
						2.9E-03	i			7664-38-2	Phosphoric acid					1.0E+01	nc				
		2.0E-05	i							7723-14-0	Phosphorus (white)	1.6E+00	nc	2.0E+01	nc			7.3E-01	nc		
		1.0E+00	h			1.0E+00	r		0.1	100-21-0	p-Phthalic acid	6.1E+04	nc	1.0E+05	max	3.7E+03	nc	3.6E+04	nc		
		2.0E+00	i			3.4E-02	h		0.1	85-44-9	Phthalic anhydride	1.0E+05	max	1.0E+05	max	1.2E+02	nc	7.3E+04	nc		
		7.0E-02	i			7.0E-02	r		0.1	1918-02-1	Picloram	4.3E+03	nc	4.3E+04	nc	2.6E+02	nc	2.6E+03	nc		
		1.0E-02	i			1.0E-02	r		0.1	29232-93-7	Pirimiphos-methyl	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
8.9E+00	h	7.0E-06	h	8.9E+00	r	7.0E-06	r		0.1		Polybrominated biphenyls	5.5E-02	ca**	1.9E-01	ca*	7.6E-04	ca*	7.6E-03	ca*		
											Polychlorinated biphenyls (PCBs, see IRIS)										
7.0E-02	i	7.0E-05	i	7.0E-02	i	7.0E-05	r		0.14	12674-11-2	PCBs (unspeciated mixture, low risk, e.g. Aroclor 1016)	3.9E+00	nc	2.1E+01	ca**	9.6E-02	ca**	9.6E-01	ca**		
2.0E+00	i	2.0E-05	i	2.0E+00	i	2.0E-05	r		0.14	11097-69-1	PCBs (unspeciated mixture, high risk, e.g. Aroclor 1254)	2.2E-01	ca**	7.4E-01	ca*	3.4E-03	ca*	3.4E-02	ca*		
4.5E+00	n			4.5E+00	r				0.1	61788-33-8	Polychlorinated terphenyls	1.1E-01	ca	3.8E-01	ca	1.5E-03	ca	1.5E-02	ca		
											Polynuclear aromatic hydrocarbons (PAHs)										
		6.0E-02	i			6.0E-02	r	y		83-32-9	Acenaphthene	3.7E+03	nc	2.9E+04	nc	2.2E+02	nc	3.7E+02	nc	5.7E+02	2.9E+01
		3.0E-01	i			3.0E-01	r	y		120-12-7	Anthracene	2.2E+04	nc	1.0E+05	max	1.1E+03	nc	1.8E+03	nc	1.2E+04	5.9E+02
7.3E-01	n			7.3E-01	r				0.13	56-55-3	Benz[a]anthracene	6.2E-01	ca	2.1E+00	ca	9.2E-03	ca	9.2E-02	ca	2.0E+00	8.0E-02
7.3E-01	n			7.3E-01	r				0.13	205-99-2	Benzo[b]fluoranthene	6.2E-01	ca	2.1E+00	ca	9.2E-03	ca	9.2E-02	ca	5.0E+00	2.0E-01
7.3E-02	n			7.3E-02	r				0.13	207-08-9	Benzo[k]fluoranthene	6.2E+00	ca	2.1E+01	ca	9.2E-02	ca	9.2E-01	ca	4.9E+01	2.0E+00
1.2E+00	c			3.9E-01	c				0.13	207-08-9	"CAL-Modified PRG"	3.8E-01	ca	1.3E+00	ca	1.7E-02	ca	5.6E-02	ca		
7.3E+00	i			7.3E+00	r				0.13	50-32-8	Benzo[a]pyrene	6.2E-02	ca	2.1E-01	ca	9.2E-04	ca	9.2E-03	ca	8.0E+00	4.0E-01
7.3E-03	n			7.3E-03	r				0.13	218-01-9	Chrysene	6.2E+01	ca	2.1E+02	ca	9.2E-01	ca	9.2E+00	ca	1.6E+02	8.0E+00
1.2E-01	c			3.9E-02	c				0.13		"CAL-Modified PRG"	3.8E+00	ca	1.3E+01	ca	1.7E-01	ca	5.6E-01	ca		
7.3E+00	n			7.3E+00	r				0.13	53-70-3	Dibenz[ah]anthracene	6.2E-02	ca	2.1E-01	ca	9.2E-04	ca	9.2E-03	ca	2.0E+00	8.0E-02
		4.0E-02	i			4.0E-02	r		0.13	206-44-0	Fluoranthene	2.3E+03	nc	2.2E+04	nc	1.5E+02	nc	1.5E+03	nc	4.3E+03	2.1E+02
		4.0E-02	i			4.0E-02	r	y		86-73-7	Fluorene	2.7E+03	nc	2.6E+04	nc	1.5E+02	nc	2.4E+02	nc	5.6E+02	2.8E+01
7.3E-01	n			7.3E-01	r				0.13	193-39-5	Indeno[1,2,3-cd]pyrene	6.2E-01	ca	2.1E+00	ca	9.2E-03	ca	9.2E-02	ca	1.4E+01	7.0E-01
		2.0E-02	i			8.6E-04	i	y		91-20-3	Naphthalene	5.6E+01	nc	1.9E+02	nc	3.1E+00	nc	6.2E+00	nc	8.4E+01	4.0E+00
1.2E-01	r			1.2E-01	c						**"CAL-Modified PRG"**	1.7E+00	ca	4.2E+00	ca	5.6E-02	ca	9.3E-02	ca		
		3.0E-02	i			3.0E-02	r	y		129-00-0	Pyrene	2.3E+03	nc	2.9E+04	nc	1.1E+02	nc	1.8E+02	nc	4.2E+03	2.1E+02
1.5E-01	i	9.0E-03	i	1.5E-01	r	9.0E-03	r		0.1	67747-09-5	Prochloraz	3.2E+00	ca	1.1E+01	ca	4.5E-02	ca	4.5E-01	ca		
		6.0E-03	h			6.0E-03	r		0.1	26399-36-0	Profluralin	3.7E+02	nc	3.7E+03	nc	2.2E+01	nc	2.2E+02	nc		
		1.5E-02	i			1.5E-02	r		0.1	1610-18-0	Prometon	9.2E+02	nc	9.2E+03	nc	5.5E+01	nc	5.5E+02	nc		
		4.0E-03	i			4.0E-03	r		0.1	7287-19-6	Prometryn	2.4E+02	nc	2.5E+03	nc	1.5E+01	nc	1.5E+02	nc		
		7.5E-02	i			7.5E-02	r		0.1	23950-58-5	Pronamide	4.6E+03	nc	4.6E+04	nc	2.7E+02	nc	2.7E+03	nc		
		1.3E-02	i			1.3E-02	r		0.1	1918-16-7	Propachlor	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		5.0E-03	i			5.0E-03	r		0.1	709-98-8	Propanil	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.0E-02	i			2.0E-02	r		0.1	2312-35-8	Propargite	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		2.0E-03	i			2.0E-03	r		0.1	107-19-7	Propargyl alcohol	1.2E+02	nc	1.2E+03	nc	7.3E+00	nc	7.3E+01	nc		
		2.0E-02	i			2.0E-02	r		0.1	139-40-2	Propazine	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		2.0E-02	i			2.0E-02	r		0.1	122-42-9	Propham	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		1.3E-02	i			1.3E-02	r		0.1	60207-90-1	Propiconazole	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
										98-82-8	Isopropylbenzene (see Cumene)										
		4.0E-02	n			4.0E-02	r	y		103-65-1	n-Propylbenzene	2.4E+02	sat	2.4E+02	sat	1.5E+02	nc	2.4E+02	nc		
		5.0E-01	p			8.6E-04	p		0.1	57-55-6	Propylene glycol	3.0E+04	nc	1.0E+05	max	3.1E+00	nc	1.8E+04	nc		
		7.0E-01	h			7.0E-01	r		0.1	52125-53-8	Propylene glycol, monoethyl ether	4.3E+04	nc	1.0E+05	max	2.6E+03	nc	2.6E+04	nc		
		7.0E-01	h			5.7E-01	i		0.1	107-98-2	Propylene glycol, monomethyl ether	4.3E+04	nc	1.0E+05	max	2.1E+03	nc	2.6E+04	nc		
2.4E-01	i	8.6E-03	r	1.3E-02	i	8.6E-03	i	y		75-56-9	Propylene oxide	1.9E+00	ca*	6.6E+00	ca*	5.2E-01	ca*	2.2E-01	ca		
		2.5E-01	i			2.5E-01	r		0.1	81335-77-5	Pursuit	1.5E+04	nc	1.0E+05	max	9.1E+02	nc	9.1E+03	nc		
		2.5E-02	i			2.5E-02	r		0.1	51630-58-1	Pydrin	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		

Key : SFo,i=Cancer Slope Factor oral, inhalation RfDo,i=Reference Dose oral, inhalation i=IRIS p=PPRTV c=California EPA n=NCEA h=HEAST x=Withdrawn r=Route-extrapolation ca=Cancer PRG nc= Noncancer PRG ca* (where: nc PRG < 100X ca PRG) ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		1.0E-03	i			1.0E-03	r		0.1	110-86-1	Pyridine	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		5.0E-04	i			5.0E-04	r		0.1	13593-03-8	Quinalphos	3.1E+01	nc	3.1E+02	nc	1.8E+00	nc	1.8E+01	nc		
3.0E+00	i			3.0E+00	r				0.1	91-22-5	Quinoline	1.6E-01	ca	5.7E-01	ca	2.2E-03	ca	2.2E-02	ca		
1.1E-01	i	3.0E-03	i	1.1E-01	r	3.0E-03	r		0.1	121-82-4	RDX (Cyclonite)	4.4E+00	ca*	1.6E+01	ca	6.1E-02	ca	6.1E-01	ca		
		3.0E-02	i			3.0E-02	r		0.1	10453-86-8	Resmethrin	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		5.0E-02	h			5.0E-02	r		0.1	299-84-3	Ronnel	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		
		4.0E-03	i			4.0E-03	r		0.1	83-79-4	Rotenone	2.4E+02	nc	2.5E+03	nc	1.5E+01	nc	1.5E+02	nc		
		2.5E-02	i			2.5E-02	r		0.1	78587-05-0	Savey	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		5.0E-03	i						0.1	7783-00-8	Selenious Acid	3.1E+02	nc	3.1E+03	nc			1.8E+02	nc		
		5.0E-03	i							7782-49-2	Selenium	3.9E+02	nc	5.1E+03	nc			1.8E+02	nc	5.0E+00	3.0E-01
		5.0E-03	h						0.1	630-10-4	Selenourea	3.1E+02	nc	3.1E+03	nc			1.8E+02	nc		
		9.0E-02	i			9.0E-02	r		0.1	74051-80-2	Sethoxydim	5.5E+03	nc	5.5E+04	nc	3.3E+02	nc	3.3E+03	nc		
		5.0E-03	i							7440-22-4	Silver and compounds	3.9E+02	nc	5.1E+03	nc			1.8E+02	nc	3.4E+01	2.0E+00
1.2E-01	h	5.0E-03	i	1.2E-01	r	5.00E-03	r		0.1	122-34-9	Simazine	4.1E+00	ca*	1.4E+01	ca	5.6E-02	ca	5.6E-01	ca		
		4.0E-03	i							26628-22-8	Sodium azide										
2.7E-01	h	3.0E-02	i	2.7E-01	r	3.0E-02	r		0.1	148-18-5	Sodium diethyldithiocarbamate	1.8E+00	ca	6.4E+00	ca	2.5E-02	ca	2.5E-01	ca		
		2.0E-05	i			2.0E-05	r		0.1	62-74-8	Sodium fluoroacetate	1.2E+00	nc	1.2E+01	nc	7.3E-02	nc	7.3E-01	nc		
		1.0E-03	h			1.0E-03	r		0.1	13718-26-8	Sodium metavanadate	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		6.0E-01	i							7440-24-6	Strontium, stable	4.7E+04	nc	1.0E+05	max			2.2E+04	nc		
		3.0E-04	i			3.0E-04	r		0.1	57-24-9	Strychnine	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
		2.0E-01	i			2.9E-01	i	y		100-42-5	Styrene	1.7E+03	sat	1.7E+03	sat	1.1E+03	nc	1.6E+03	nc	4.0E+00	2.0E-01
		5.0E-03	p			5.0E-03	r			80-07-9	**1,1'-Sulfonylbis (4-chlorobenzene)**	3.9E+02	nc	5.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		2.5E-02	i			2.5E-02	r		0.1	88671-89-0	Systhane	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
1.5E+05	h			1.5E+05	h				0.03	1746-01-6	2,3,7,8-TCDD (dioxin)	3.9E-06	ca	1.6E-05	ca	4.5E-08	ca	4.5E-07	ca		
		7.0E-02	i			7.0E-02	r		0.1	34014-18-1	Tebuthiuron	4.3E+03	nc	4.3E+04	nc	2.6E+02	nc	2.6E+03	nc		
		2.0E-02	h			2.0E-02	r		0.1	3383-96-8	Temephos	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
		1.3E-02	i			1.3E-02	r		0.1	5902-51-2	Terbacil	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		2.5E-05	h			2.5E-05	r		0.1	13071-79-9	Terbufos	1.5E+00	nc	1.5E+01	nc	9.1E-02	nc	9.1E-01	nc		
		1.0E-03	i			1.0E-03	r		0.1	886-50-0	Terbutryn	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		3.0E-04	i			3.0E-04	r		0.1	95-94-3	1,2,4,5-Tetrachlorobenzene	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
2.6E-02	i	3.0E-02	i	2.6E-02	i	3.0E-02	r	y		630-20-6	1,1,1,2-Tetrachloroethane	3.2E+00	ca	7.3E+00	ca	2.6E-01	ca	4.3E-01	ca		
2.0E-01	i	6.0E-02	p	2.0E-01	i	6.0E-02	r	y		79-34-5	1,1,2,2-Tetrachloroethane	4.1E-01	ca	9.3E-01	ca	3.3E-02	ca	5.5E-02	ca	3.0E-03	2.0E-04
5.4E-01	c	1.0E-02	i	2.1E-02	c	1.0E-02	c	y		127-18-4	**Tetrachloroethylene (PCE)**	4.8E-01	ca*	1.3E+00	ca	3.2E-01	ca	1.0E-01	ca	6.0E-02	3.0E-03
		3.0E-02	i			3.0E-02	r		0.1	58-90-2	2,3,4,6-Tetrachlorophenol	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
2.0E+01	h			2.0E+01	r				0.1	5216-25-1	p,a,a,a-Tetrachlorotoluene	2.4E-02	ca	8.6E-02	ca	3.4E-04	ca	3.4E-03	ca		
2.4E-02	h	3.0E-02	i	2.4E-02	r	3.0E-02	r		0.1	961-11-5	Tetrachlorovinphos	2.0E+01	ca*	7.2E+01	ca	2.8E-01	ca	2.8E+00	ca		
		5.0E-04	i			5.0E-04	r		0.1	3689-24-5	Tetraethyldithiopyrophosphate	3.1E+01	nc	3.1E+02	nc	1.8E+00	nc	1.8E+01	nc		
7.6E-03	n	2.1E-01	n	6.8E-03	n	8.6E-02	n	y		109-99-9	Tetrahydrofuran	9.4E+00	ca	2.1E+01	ca	9.9E-01	ca	1.6E+00	ca		
		6.6E-05	i							7440-28-0	Thallium and compounds+++	5.2E+00	nc	6.7E+01	nc			2.4E+00	nc		
		1.0E-02	i			1.0E-02	r		0.1	28249-77-6	Thiobencarb	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		5.0E-02	n			5.0E-02	r		0.1	N/A	Thiocyanate	3.1E+03	nc	1.0E+05	max	1.8E+02	nc	1.8E+03	nc		
		3.0E-04	h			3.0E-04	r		0.1	39196-18-4	Thiofanox	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		

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TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		8.0E-02	i			8.0E-02	r		0.1	23564-05-8	Thiophanate-methyl	4.9E+03	nc	4.9E+04	nc	2.9E+02	nc	2.9E+03	nc		
		5.0E-03	i			5.0E-03	r		0.1	137-26-8	Thiram	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
		6.0E-01	h							7440-31-5	Tin (inorganic, also see tributyltin oxide)	4.7E+04	nc	1.0E+05	max			2.2E+04	nc		
		4.0E+00	n			8.6E-03	n			7440-32-6	Titanium	1.0E+05	max	1.0E+05	max	3.1E+01	nc	1.5E+05	nc		
		2.0E-01	i			1.1E-01	i	y		108-88-3	Toluene	5.2E+02	sat	5.2E+02	sat	4.0E+02	nc	7.2E+02	nc	1.2E+01	6.0E-01
3.2E+00	h			3.2E+00	r				0.1	95-80-7	Toluene-2,4-diamine	1.5E-01	ca	5.4E-01	ca	2.1E-03	ca	2.1E-02	ca		
		6.0E-01	h			6.0E-01	r		0.1	95-70-5	Toluene-2,5-diamine	3.7E+04	nc	1.0E+05	max	2.2E+03	nc	2.2E+04	nc		
		2.0E-01	h			2.0E-01	r		0.1	823-40-5	Toluene-2,6-diamine	1.2E+04	nc	1.0E+05	max	7.3E+02	nc	7.3E+03	nc		
1.9E-01	i			1.9E-01	r				0.1	106-49-0	p-Toluidine	2.6E+00	ca	9.1E+00	ca	3.5E-02	ca	3.5E-01	ca		
1.1E+00	i			1.1E+00	i				0.1	8001-35-2	Toxaphene	4.4E-01	ca	1.6E+00	ca	6.0E-03	ca	6.1E-02	ca	3.1E+01	2.0E+00
		7.5E-03	i			7.5E-03	r		0.1	66841-25-6	Tralomethrin	4.6E+02	nc	4.6E+03	nc	2.7E+01	nc	2.7E+02	nc		
		1.3E-02	i			1.3E-02	r		0.1	2303-17-5	Triallate	7.9E+02	nc	8.0E+03	nc	4.7E+01	nc	4.7E+02	nc		
		1.0E-02	i			1.0E-02	r		0.1	82097-50-5	Triasulfuron	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		5.0E-03	i			5.0E-03	r		0.1	615-54-3	1,2,4-Tribromobenzene	3.1E+02	nc	3.1E+03	nc	1.8E+01	nc	1.8E+02	nc		
9.2E-03	p	2.0E-01	p	9.2E-03	r	2.0E-01	r		0.1	126-73-8	**Tributyl phosphate**	5.3E+01	ca	1.9E+02	ca	7.3E-01	ca	7.3E+00	ca		
		3.0E-04	i						0.1	56-35-9	Tributyltin oxide (TBTO)	1.8E+01	nc	1.8E+02	nc			1.1E+01	nc		
3.4E-02	h			3.4E-02	r				0.1	634-93-5	2,4,6-Trichloroaniline	1.4E+01	ca	5.1E+01	ca	2.0E-01	ca	2.0E+00	ca		
2.9E-02	h			2.9E-02	r				0.1	33663-50-2	2,4,6-Trichloroaniline hydrochloride	1.7E+01	ca	5.9E+01	ca	2.3E-01	ca	2.3E+00	ca		
		1.0E-02	i			1.0E-03	p	y		120-82-1	**1,2,4-Trichlorobenzene**	6.2E+01	nc	2.2E+02	nc	3.7E+00	nc	7.2E+00	nc	5.0E+00	3.0E-01
		2.8E-01	n			6.3E-01	p	y		71-55-6	1,1,1-Trichloroethane	1.2E+03	sat	1.2E+03	sat	2.3E+03	nc	3.2E+03	nc	2.0E+00	1.0E-01
5.7E-02	i	4.0E-03	i	5.6E-02	i	4.0E-03	r	y		79-00-5	1,1,2-Trichloroethane	7.3E-01	ca*	1.6E+00	ca*	1.2E-01	ca	2.0E-01	ca	2.0E-02	9.0E-04
4.0E-01	n	3.0E-04	n	4.0E-01	n	1.0E-02	n	y		79-01-6	Trichloroethylene (TCE)	5.3E-02	ca	1.1E-01	ca	1.7E-02	ca	2.8E-02	ca	6.0E-02	3.0E-03
1.3E-02	c			7.0E-03	c	1.7E-01	c	y		79-01-6	**"CAL-Modified PRG"**	2.9E+00	ca	6.5E+00	ca	9.6E-01	ca	1.4E+00	ca		
		3.0E-01	i			2.0E-01	h	y		75-69-4	Trichlorofluoromethane	3.9E+02	nc	2.0E+03	sat	7.3E+02	nc	1.3E+03	nc		
		1.0E-01	i			1.0E-01	r		0.1	95-95-4	2,4,5-Trichlorophenol	6.1E+03	nc	6.2E+04	nc	3.7E+02	nc	3.6E+03	nc	2.7E+02	1.4E+01
1.1E-02	i	1.0E-04	n	1.1E-02	i	1.0E-04	r		0.1	88-06-2	2,4,6-Trichlorophenol	6.1E+00	nc**	6.2E+01	nc**	3.7E-01	nc**	3.6E+00	nc**	2.0E-01	8.0E-03
7.0E-02	c			7.0E-02	c				0.1	88-06-2	"CAL-Modified PRG"	6.9E+00	ca	2.5E+01	ca	9.6E-02	ca	9.6E-01	ca		
		1.0E-02	i			1.0E-02	r		0.1	93-76-5	2,4,5-Trichlorophenoxyacetic Acid	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
		8.0E-03	i			8.0E-03	r		0.1	93-72-1	2-(2,4,5-Trichlorophenoxy) propionic acid	4.9E+02	nc	4.9E+03	nc	2.9E+01	nc	2.9E+02	nc		
		5.0E-03	i			5.0E-03	r	y		598-77-6	**1,1,2-Trichloropropane**	7.1E+01	nc	2.7E+02	nc	1.8E+01	nc	3.0E+01	nc		
2.0E+00	n	6.0E-03	i	2.0E+00	r	1.4E-03	n	y		96-18-4	**1,2,3-Trichloropropane**	3.4E-02	ca	7.6E-02	ca	3.4E-03	ca	5.6E-03	ca		
		1.0E-02	p			3.0E-04	p	y		96-19-5	**1,2,3-Trichloropropene**	5.2E+00	nc	1.7E+01	nc	1.1E+00	nc	2.2E+00	nc		
		3.0E-03	i			3.0E-03	r		0.1	58138-08-2	Tridiphane	1.8E+02	nc	1.8E+03	nc	1.1E+01	nc	1.1E+02	nc		
		2.0E-03	r			2.0E-03	i	y		121-44-8	Triethylamine	2.3E+01	nc	8.6E+01	nc	7.3E+00	nc	1.2E+01	nc		
7.7E-03	i	7.5E-03	i	7.7E-03	r	7.5E-03	r		0.1	1582-09-8	Trifluralin	6.3E+01	ca**	2.2E+02	ca*	8.7E-01	ca*	8.7E+00	ca*		
		1.4E-04	r			1.4E-04	n		0.1	552-30-7	Trimellitic Anhydride (TMAN)	8.6E+00	nc	8.6E+01	nc	5.1E-01	nc	5.1E+00			
		5.0E-02	p			1.7E-03	p	y		95-63-6	1,2,4-Trimethylbenzene	5.2E+01	nc	1.7E+02	nc	6.2E+00	nc	1.2E+01	nc		
		5.0E-02	p			1.7E-03	p	y		108-67-8	1,3,5-Trimethylbenzene	2.1E+01	nc	7.0E+01	nc	6.2E+00	nc	1.2E+01	nc		
3.7E-02	h			3.7E-02	r				0.1	512-56-1	Trimethyl phosphate	1.3E+01	ca	4.7E+01	ca	1.8E-01	ca	1.8E+00	ca		
		3.0E-02	i			3.0E-02	r		0.1	99-35-4	1,3,5-Trinitrobenzene	1.8E+03	nc	1.8E+04	nc	1.1E+02	nc	1.1E+03	nc		
		1.0E-02	h			1.0E-02	r		0.1	479-45-8	Trinitrophenylmethylnitramine	6.1E+02	nc	6.2E+03	nc	3.7E+01	nc	3.6E+02	nc		
3.0E-02	i	5.0E-04	i	3.0E-02	r	5.0E-04	r		0.1	118-96-7	2,4,6-Trinitrotoluene	1.6E+01	ca**	5.7E+01	ca**	2.2E-01	ca**	2.2E+00	ca**		

Key : SFo,i=Cancer Slope Factor oral, inhalation RfDo,i=Reference Dose oral, inhalation i=IRIS p=PPRTV c=California EPA n=NCEA h=HEAST x=Withdrawn r=Route-extrapolation ca=Cancer PRG nc= Noncancer PRG ca* (where: nc PRG < 100X ca PRG) ca** (where nc PRG < 10X ca PRG) +++=Non-Standard Method Applied (See User's Guide) sat=Soil Saturation (See User's Guide) max=Ceiling limit (See User's Guide) DAF=Dilution Attenuation Factor (See User's Guide) CAS=Chemical Abstract Services

TOXICITY VALUES											CONTAMINANT	PRELIMINARY REMEDIATION GOALS (PRGs) "Direct Contact Exposure Pathways"								SOIL SCREENING LEVELS "Migration to Ground Water"	
SFo 1/(mg/kg-d)		RfDo (mg/kg-d)		SFi 1/(mg/kg-d)		RfDi (mg/kg-d)		VOC	skin abs. soils	CAS No.		Residential Soil (mg/kg)		Industrial Soil (mg/kg)		Ambient Air (ug/m^3)		Tap Water (ug/l)		DAF 20 (mg/kg)	DAF 1 (mg/kg)
		2.0E-02	p			2.0E-02	r		0.1	791-28-6	**Triphenylphosphine oxide**	1.2E+03	nc	1.2E+04	nc	7.3E+01	nc	7.3E+02	nc		
1.4E-02	p	3.1E-01	p	1 4E-02	r	3.1E-01	r		0.1	115-96-8	**Tris(2-chloroethyl) phosphate**	3.5E+01	ca	1.2E+02	ca	4.8E-01	ca	4.8E+00	ca		
3.2E-03	p	1.0E-01	p	3.2E-03	r	1.0E-01	r		0.1	78-42-2	**Tris(2-ethylhexyl) phosphate**	1.5E+02	ca*	5.4E+02	ca	2.1E+00	ca	2.1E+01	ca		
		2.0E-04	n							7440-61-1	Uranium (chemical toxicity only)	1.6E+01	nc	2.0E+02	nc			7.3E+00	nc		
		1.0E-03	n							7440-62-2	Vanadium and compounds	7.8E+01	nc	1.0E+03	nc			3.6E+01	nc	6.0E+03	3.0E+02
		1.0E-03	i			1.0E-03	r		0.1	1929-77-7	Vernam	6.1E+01	nc	6.2E+02	nc	3.7E+00	nc	3.6E+01	nc		
		2.5E-02	i			2.5E-02	r		0.1	50471-44-8	Vinclozolin	1.5E+03	nc	1.5E+04	nc	9.1E+01	nc	9.1E+02	nc		
		1.0E+00	h			5.7E-02	i	y		108-05-4	Vinyl acetate	4.3E+02	nc	1.4E+03	nc	2.1E+02	nc	4.1E+02	nc	1.7E+02	8.0E+00
1.1E-01	r	8 6E-04	r	1.1E-01	h	8.6E-04	i	y		593-60-2	Vinyl bromide (bromoethene)	1.9E-01	ca*	4.2E-01	ca*	6.1E-02	ca*	1.0E-01	ca*		
1 5E+00	i	3.0E-03	i	3.1E-02	i	2.9E-02	i	y		75-01-4	Vinyl chloride (child/adult)+++	7.9E-02	ca			1.1E-01	ca	2.0E-02	ca	1.0E-02	7.0E-04
7.5E-01	i	3.0E-03	i	1.6E-02	i	2.9E-02	i	y		75-01-4	Vinyl chloride (adult)			7.5E-01	ca						
		3.0E-04	i			3.0E-04	r		0.1	81-81-2	Warfarin	1.8E+01	nc	1.8E+02	nc	1.1E+00	nc	1.1E+01	nc		
		2.0E-01	i			2.9E-02	i	y	0.1	1330-20-7	**Xylenes**	2.7E+02	nc	4.2E+02	sat	1.1E+02	nc	2.1E+02	nc	2.1E+02	1.0E+01
		3.0E-01	i							7440-66-6	Zinc	2.3E+04	nc	1.0E+05	max			1.1E+04	nc	1.2E+04	6.2E+02
		3.0E-04	i							1314-84-7	Zinc phosphide	2.3E+01	nc	3.1E+02	nc			1.1E+01	nc		
		5.0E-02	i			5.0E-02	r		0.1	12122-67-7	Zineb	3.1E+03	nc	3.1E+04	nc	1.8E+02	nc	1.8E+03	nc		

Reference 13

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Hydrology of the Floridan Aquifer System in Southeast Georgia and Adjacent Parts of Florida and South Carolina

By RICHARD E. KRAUSE *and* ROBERT B. RANDOLPH

REGIONAL AQUIFER-SYSTEM ANALYSIS—FLORIDAN AQUIFER SYSTEM

U. S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403 – D

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1989

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS

Factors for converting inch-pound units to the International System (SI) of units are given below:

Multiply	*By*	*To obtain*
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	3.785×10^{-3}	cubic meter (m^3)
	Flow	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	6.309×10^{-5}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Leakance	
gallon per day per cubic foot [(gal/d)/ft^3]	0.1337	meter per day per meter [(m/d)/m]
foot per day per foot [(ft/d)/ft] (or in reduced form, day^{-1})	1.000	meter per day per meter [(m/d)/m]
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Drawdown	
foot per year (ft/yr)	0.3048	meter per year (m/yr)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

HYDROLOGY OF THE FLORIDAN AQUIFER SYSTEM IN SOUTHEAST GEORGIA AND ADJACENT PARTS OF FLORIDA AND SOUTH CAROLINA

By RICHARD E. KRAUSE and ROBERT B. RANDOLPH

ABSTRACT

The ground-water flow of the Floridan aquifer system under predevelopment (about 1880) and present-day (1980) conditions in southeast Georgia and adjacent parts of Florida and South Carolina was simulated using a three-dimensional finite-difference digital model. The model was used to better define the hydrogeology and ground-water flow system in the Floridan aquifer system in that area.

The Floridan aquifer system, known as the principal artesian aquifer in Georgia, South Carolina, and Alabama, and as the Floridan aquifer in Florida, consists of interbedded clastics and marl in the updip area and massive limestone and dolomite more than 2,000 feet thick in the downdip area. The Floridan aquifer system, primarily of Eocene age, is hydraulically connected in varying degrees but has been divided into the Upper and Lower Floridan aquifers in most of the study area. In southeast Georgia and northeast Florida, the Lower Floridan includes a basal unit herein formally designated the "Fernandina permeable zone." The Floridan, in most of the area, is confined above by clay beds of the Miocene Hawthorn Formation. Low-permeability clastic, evaporitic, or carbonate rocks form the base of the aquifer system.

The Floridan is heterogeneous; transmissivity of the Upper Floridan ranges from nearly zero near the aquifer's updip extent to about 1 million feet squared per day in the cavernous thick carbonate sequence in south Georgia. Areally, the Floridan is traversed by the Gulf Trough, a structurally controlled, clastic-infilled series of grabens, approximately aligned along strike. This feature is an important control on the regional flow system; it impedes flow from the upgradient, primarily clastic part to the downgradient, massive carbonate part of the Floridan.

Simulation results indicate that a total of about 900 million gallons per day (1,400 cubic feet per second) of water flowed through the aquifer system prior to development. About two-thirds of this flow was in the area upgradient from the Gulf Trough. This flow consisted of recharge in areas between streams, lateral movement downgradient, and discharge to the major rivers. The flow system in most of the area downgradient from the Gulf Trough was characterized by slow lateral movement resulting from low diffuse recharge and discharge. Throughout the study area, almost all circulation was within the Upper Floridan.

Pumpage from the aquifer system, totaling about 625 million gallons per day (970 cubic feet per second) in 1980 and concentrated primarily in the areas downgradient from the Gulf Trough, changed the flow system markedly. The flow system was nearly unchanged upgradient from the Gulf Trough, where less than 5 percent of the pumpage occurred. Downgradient from the trough, large ground-water withdrawals concentrated along the coast, primarily from the Upper Floridan, caused significant head declines. These head declines caused lateral and vertical gradient changes and reversals, increased circulation in, and upward leakage from, the Lower Floridan and the Fernandina permeable zone, a local degradation in water quality, and land subsidence. Although not tapped by producing wells, the Fernandina permeable zone provided about 180 million gallons per day (280 cubic feet per second) of water to the coastal pumpage through solution-enlarged faults breaching the confining beds. The quality of the water in the Fernandina permeable zone ranged from fresh to brine, locally contaminating the Upper Floridan, most notably in Brunswick, Georgia. Model-simulated flow through the Floridan aquifer system under present-day (1980) conditions totaled about 1,350 million gallons per day (2,100 cubic feet per second).

Although heavily developed along the coast, the Floridan could withstand some additional development, especially inland, as indicated by simulations involving future hypothetical pumping schemes. The area around Waycross, Georgia, could probably undergo additional development of more than 26 million gallons per day (about 40 cubic feet per second), but in some places along the coast, where heavy withdrawals have already posed water-quality problems, additional development probably could not occur without detrimental effects to the system.

INTRODUCTION

The Floridan aquifer system, known as the principal artesian aquifer in Georgia, Alabama, and South Carolina and as the Floridan aquifer in Florida, is the major source of water in the area of its occurrence, except where it contains saline water. About 625 Mgal/d (970 ft^3/s) of water was withdrawn from the aquifer in 1980 for industrial, municipal, agricultural, and other uses in the eastern half of the Coastal Plain of Georgia, northeast Florida, and the southern part of South Carolina. Problems that have developed because of this

heavy withdrawal are (1) decline in water levels, chiefly around pumping centers, but areawide as well, (2) highly mineralized water induced into the aquifer from underlying strata, (3) seawater moving toward pumping centers from offshore, and (4) land subsidence.

In 1978, the U.S. Geological Survey began a study of the Floridan aquifer system on a regional scale under its Regional Aquifer-System Analysis (RASA) program. The RASA program represents a systematic effort to study a number of regional aquifers which together cover much of the country and provide a significant part of the Nation's water supply. (See fig. 1 in chapter A of this Professional Paper series (Johnston and Bush, in press) for the location of these regional aquifers.) The overall objectives of the Floridan aquifer-system study include (1) a complete description of the hydrogeologic framework and geochemistry of the entire aquifer system, (2) an analysis of the ground-water flow through the aquifer system, (3) an assessment of the effects of large withdrawals of ground water on the aquifer, and (4) an appraisal of water-management alternatives. The study is regional in scope, and the aquifer system is defined in its entirety, without regard to political subdivisions.

Components of the Floridan aquifer-system analysis were divided on the basis of discipline, as well as areally. Areal subdivisions were based on the similarity of hydrologic features and problems and on the location of natural hydrologic boundaries within the aquifer system (fig. 1). Results of the study are being published as separate chapters in this Professional Paper series as follows:

A. Summary of the hydrology of the Floridan aquifer system
B. Hydrogeologic framework of the Floridan aquifer system
C. Regional hydrology and ground-water development of the Floridan aquifer system
D–H. Hydrology of the Floridan aquifer system:
   D. In southeast Georgia and adjacent parts of Florida and South Carolina (this report)
   E. In east-central Florida
   F. In west-central Florida
   G. In south Florida
   H. In southwest Georgia, northwest Florida, and extreme south Alabama
I. Geochemistry of the Floridan aquifer system.

Chapter A summarizes the hydrogeologic framework, hydraulic characteristics, and geochemistry of the aquifer system.

Chapter B describes the geologic framework and hydrogeologic characteristics of the aquifer system. Maps, sections, and fence diagrams show the relations of lithofacies, structure, thickness, and stratigraphy to aquifer and confining-unit geometry.

Chapter C presents a description of the regional flow system based on digital simulation and discusses ground-water development on a regional scale.

Chapters D–H present descriptions of the ground-water hydrology of the subregions emphasizing local hydrologic features and development.

Chapter I describes the natural geochemistry of the aquifer system. Maps, sections, phase diagrams, and tables are used to explain the occurrence of the hydrochemical facies, the relation between natural changes in water chemistry and the flow system, and geochemical changes induced by pumping and land development.

HISTORICAL TERMINOLOGY OF THE FLORIDAN AQUIFER SYSTEM

The existence of a regional flow system in what is herein called the Floridan aquifer system was first described in some detail in peninsular Florida by Stringfield (1936, p. 132, pl. 12). Warren (1944, p. 17) described the extension of this flow system in southeastern Georgia and applied the term "principal artesian aquifer" to the carbonate units involved (table 1). Stringfield (1966, p. 95) used the term "principal artesian aquifer" to describe the permeable carbonate rocks from the lower part of the Hawthorn Formation through the Oldsmar Limestone in Georgia and South Carolina, as well as in Florida and Alabama. The term "principal artesian aquifer" as defined by Stringfield has been used in Georgia and South Carolina.

Parker (in Parker and others, 1955, p. 188, 189) described the limestone units from the basal part of the Hawthorn Formation through middle Eocene (Lake City) limestone and named that sequence the "Floridan aquifer." The term "Floridan aquifer" is entrenched in the Florida ground-water literature and is also widely used in national and international publications.

Cederstrom and others (1979, p. 8, 14) referred to the aquifer as the "Tertiary limestone aquifer." Their designation of the aquifer includes rocks, primarily carbonates, of the Tampa Limestone through the Oldsmar Limestone.

During the regional study of the Floridan aquifer system, Miller used the term "Tertiary limestone aquifer system," which combined the age of the rocks and their general lithology, as the name of the aquifer system (Miller, 1982a, b, c, d, e). By the end of the study, the term "Floridan aquifer system" was formally applied to the aquifer system (Miller, 1985). The term "Floridan aquifer system" is uniformly used in all chapters of this Professional Paper series and is proposed

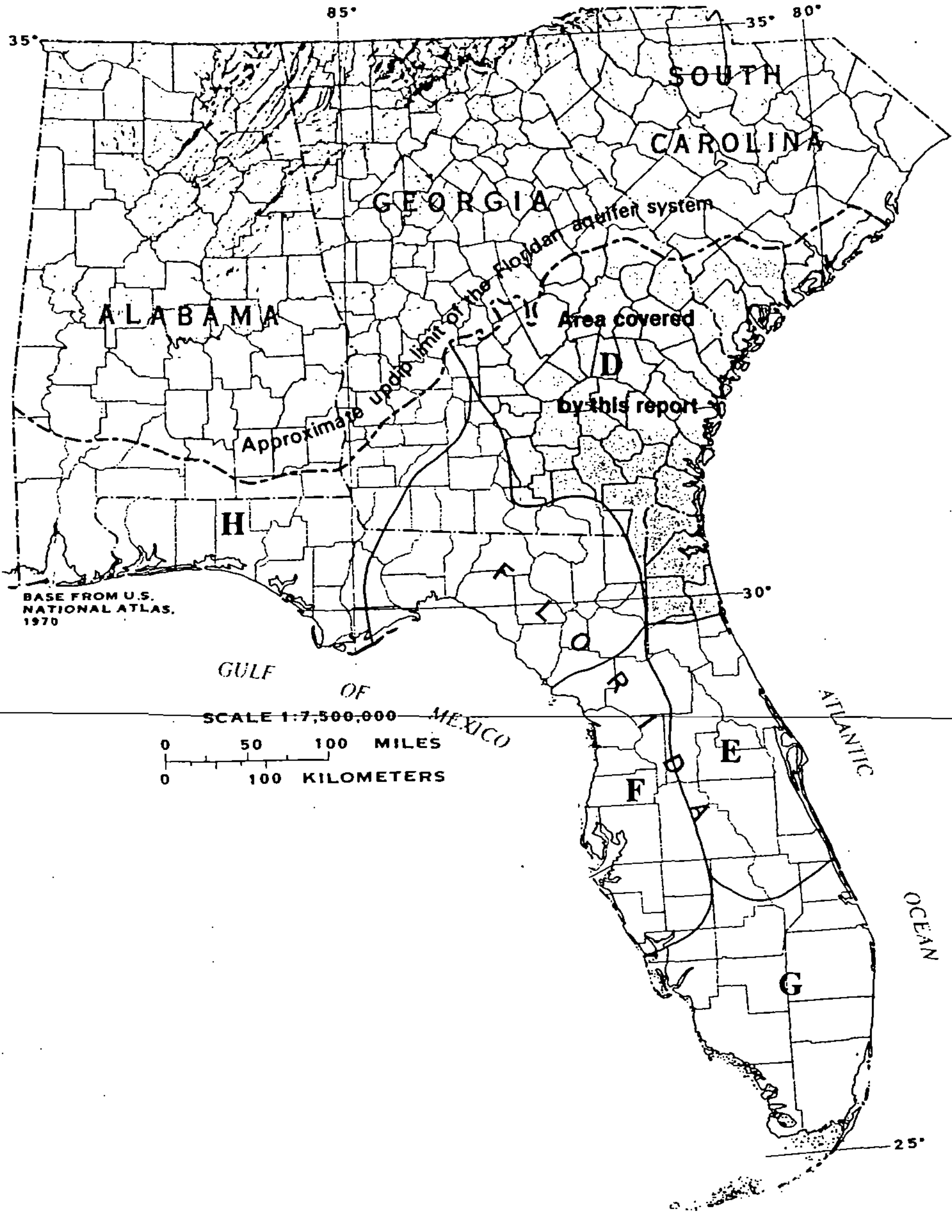


FIGURE 1.—Location of Floridan aquifer system study area, subregional project areas, and chapter designations in Professional Paper 1403.

for use in further investigations of the aquifer system. Because distinct, regionally mappable hydrogeologic units occur within the carbonate sequence, the term "aquifer system" is preferred to "aquifer." Use of "system" follows Poland and others (1972, p. 2), who stated that an aquifer system "* * * comprises two or more permeable beds separated at least locally by [confining beds] that impede ground-water movement but do not greatly affect the regional hydraulic continuity of the system." This definition applies to the Floridan aquifer system throughout most of its area of occurrence. (See table 1 for a summary of historical terminology and stratigraphy applied to the Floridan aquifer system.)

PURPOSE AND SCOPE

The overall purpose of this study was to describe the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina. Specifically, the objectives of the study were to (1) describe and

TABLE 1.—*Summary of historical terminology applied to the Floridan aquifer system*

Series		Formation[1]	Warren (1944)	Parker and others (1955)	Stringfield (1966)	Cederstrom and others (1979)	Miller (1982b, 1982d)	This report[2]
Miocene		Hawthorn Formation		Where permeable	Principal artesian aquifer			
Miocene		Tampa Limestone		Floridan aquifer		Where present and permeable	Where present and permeable	
Oligocene		Suwannee Limestone	Principal artesian aquifer			Tertiary limestone aquifer	Tertiary limestone aquifer system	Floridan aquifer system[3]
Eocene	Upper	Ocala Limestone						
Eocene	Middle	Avon Park Formation[2,4]						
Eocene	Lower	Oldsmar Formation[2,5]						
Paleocene		Cedar Keys Formation[2,6]						

[1] Principal, most areally extensive formations representative of the downdip area.
[2] Based on Miller (1985), Professional Paper 1403-B.
[3] Tampa Limestone absent in the study area; rocks of Late Cretaceous age form the lowermost part of the aquifer system locally in the Brunswick, Ga., area.
[4] Formerly Avon Park Limestone and Lake City Limestone
[5] Formerly Oldsmar Limestone.
[6] Formerly Cedar Keys Limestone.

delineate the hydrogeologic framework of the aquifer system, (2) describe the flow system prior to development, (3) describe the present-day (1980) flow system and the changes that occurred as a result of development, (4) determine the potential for additional development, and (5) describe the quality of water in the aquifer system and its relation to present-day stresses.

This report describes the results of the study and relates to the other chapters of this Professional Paper series as stated below.

The hydrogeologic framework of the aquifer system as it relates to the ground-water-flow system in the study area is described and delineated in this report. A detailed description of the hydrogeologic framework on a regional scale is presented by Miller (1985) in chapter B of this Professional Paper series. The hydrogeologic framework described herein is largely that of Miller's chapter B; however, some differences exist because of the difference between the regional and the local scales. The local hydrogeologic units are subdivisions of larger units that make up the regional hydrogeologic framework.

The predevelopment and present-day flow systems of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina are described quantitatively in this report. In chapter C of this Professional Paper series, Bush and Johnston (in press) describe the flow system on a less detailed, regional scale. A one-to-one correlation of the quantitative results described in this report and in Bush and Johnston's report cannot be made because of the difference in simulation scale. However, the simulations described in both reports are based on the same set of data.

Determinations of the potential for additional ground-water development from the Floridan aquifer system in the study area are included in this report. Computer simulations, as well as existing information on the hydrology and water quality, provided the basis for the analysis. Bush and Johnston (in press) also include a section on development potential, but it is of lesser detail and is more general in scope.

Only a general description of the geochemistry of the Floridan aquifer system in the study area is included in this report. The quality of the water in areas where it is found to be locally of poor quality is described in greater detail. In these areas, the poor-water-quality features are related to the flow system as it existed prior to development, and as it exists as a result of ground-water development. A more detailed description of the geochemistry of the entire aquifer system is discussed in chapter I of this Professional Paper series (Sprinkle, in press). However, water-quality anomalies or local problems are discussed only in a general way in chapter I.

APPROACH AND METHODS

The hydrogeologic framework of the Floridan aquifer system was determined chiefly by Miller (1985), who delineated the aquifer system on the basis of lithologic, paleontologic, and hydrologic data determined from selected wells. These data were correlated with geophysical well-logs and were extrapolated throughout the study area.

Most of the hydrologic data used in this study were available from previous investigations and ground-water monitoring programs. Sources of the data, some of which dated back to the late 1800's, were the published literature, files containing unpublished data in the form of tables, maps, graphs, and logs, and the more recent computer data bases.

The types of data assembled and used in the analysis and simulation of the flow system included the following: (1) precipitation, streamflow, evapotranspiration (derived from rainfall, pan-evaporation, and temperature data), used for determining recharge and discharge rates; (2) aquifer characteristics, including thickness, specific capacity, hydraulic conductivity, and transmissivity; (3) hydraulic head; (4) confining-unit characteristics, including thickness, vertical hydraulic conductivity, and leakage coefficients; and (5) water use.

Most of the water-quality data used in the description of the geochemistry of, and quality of water from, the aquifer system were collected and published as part of previous investigations and water-quality monitoring programs. Interpretations of water quality were focused primarily on local anomalies, such as concentration of chloride in the areas of saltwater encroachment.

The gathering of new field data was limited to selected areas and activities to fill specific data voids, as follows:

1. Two wells penetrating the entire Floridan aquifer system were drilled near Waycross, Ga. Geologic, geophysical, hydrologic, and water-quality data were collected from coring, logging, packer testing, aquifer testing, and water sampling. Results are reported by Matthews and Krause (1984).
2. An offshore oil-test well abandoned in 1979 was used for data collection, including drill-stem testing. Geologic, geophysical, hydrologic, and water-quality data were collected and analyzed, and were reported by Johnston and others (1982).
3. In May 1980, synoptic water-level measurements were made in approximately 500 wells tapping the Floridan aquifer system in the study area. The resulting potentiometric surface provided information on the present-day (1980) flow system and was used for model calibration. The map and the related information were reported by Johnston and others (1981).
4. Geophysical logging was done in selected wells where data were lacking to provide better definition of the hydrogeologic framework.

The principal method of analysis of the Floridan aquifer system was computer simulation. Computer simulation was used to (1) identify the types of data that are needed to understand the flow system, and to indicate what data were lacking, (2) provide a working hypothesis for testing and evaluating various concepts of the flow system, and (3) provide a tool that can be used to evaluate alternative methods of resource management and to estimate the development potential of the aquifer system.

The computer model used in this analysis is a quasi-three-dimensional, finite-difference code that simulates lateral flow within aquifers and leakage vertically across confining units. All components of the flow system within the Floridan aquifer system, as well as hydrologic units that are adjacent to it and that affect it hydrologically, are part of the simulation.

LOCATION AND EXTENT OF STUDY AREA

The hydrogeologic investigation covers an area of about 30,000 mi^2 in southeast Georgia and adjacent parts of Florida and South Carolina, of which 10,000 mi^2 is offshore (fig. 1).

The extent of the study area is based on natural hydrologic boundaries. The western and southern boundaries were delineated on the basis of ground-water divides. The northern boundary is the outcrop area and updip limit of the aquifer system. The eastern boundary is the easternmost limit of the aquifer system in South Carolina or the freshwater–saltwater interface offshore in Georgia and part of South Carolina.

PREVIOUS INVESTIGATIONS

The hydrogeology of the Floridan aquifer system in southeast Georgia and in parts of Florida and South Carolina has been investigated extensively in the areas of greatest development. However, these studies are restricted almost entirely to a narrow band between the coastal cities of Savannah, Ga., and Jacksonville, Fla., which represents less than 15 percent of the area included in this study. Among the more recent and comprehensive hydrogeologic investigations in this coastal area are those by Hayes (1979) and Spigner and Ransom (1979) in the Low Country (southern part) of South Carolina, Counts and Donsky (1963) in the area of Savannah, Ga., Dyar, Tasker, and Wait (1972) and Krause (1972) in parts of Liberty and McIntosh Counties, Ga., Wait and Gregg (1973) and Gregg and Zimmerman (1974) in the area of Brunswick, Ga., and Bermes, Leve,

and Tarver (1963), Leve (1966) and Snell and Anderson (1970) in the northeast Florida area. Paull and Dillon (1979) provide a description of the geology and hydrogeology of the offshore area, the Florida–Hatteras Shelf and Slope, and the Inner Blake Plateau.

Inland from the coastal area, almost no hydrogeologic investigations have been conducted and data are lacking. One exception was an investigation by Krause (1979) of the hydrogeology of the area of Valdosta, Ga., on the western limit of this study.

Callahan (1964), using existing data, included most of the study area in a report on the Coastal Plain aquifers in Georgia and parts of northeast Florida and southern South Carolina. Stringfield (1966) is the most comprehensive reference on the water from Tertiary limestone in the Southeastern States.

Only in two areas has the ground-water-flow system been studied by using computer simulations. The studies were in Georgia, in the areas of Brunswick (Krause and Counts, 1975) and Savannah (Counts and Krause, 1976; Randolph and Krause, 1984). The simulation models, although only two-dimensional in scope, serve as management tools for evaluating declines in the water level and deterioration of water quality due to heavy pumping.

The regional aquifer-system study of the Floridan aquifer system has generated several reports in addition to those in this Professional Paper series. These reports, all covering the Floridan aquifer system on a regional scale, describe the hydrogeologic framework of the aquifer system (Miller, 1982a, b, c, d, e); the geochemistry and ground-water quality (Sprinkle, 1982a, b, c, d); the estimated potentiometric surface prior to development (Johnston and others, 1980); and the potentiometric surface for present-day (May 1980) conditions (Johnston and others, 1981).

Results of test drilling and aquifer testing conducted during this investigation have been reported. Included are (1) results of hydrologic testing in an abandoned oil exploratory hole on the Atlantic Outer Continental Shelf (Johnston and others, 1982), (2) geologic and hydrologic data from a test-monitor well at Fernandina Beach, Fla. (Brown, 1980), (3) geologic and hydrologic results of test drilling and aquifer testing near Waycross, Ga. (Matthews and Krause, 1984), and (4) geologic and hydrologic data gathered from test drilling at Jacksonville Beach, Fla. (Brown and others, 1984).

The predevelopment flow system in the study area was described by Krause (1982) as part of this study. The report documents the initial phase of this study: model design, calibration, and results of computer simulation of the aquifer flow system prior to development. Because the report was preliminary in scope, conceptualization of the aquifer system was more general than that reported herein. In effect, the preliminary report describes a working conceptual model and consequent simulation of the predevelopment flow system in the Floridan. However, simulation of the present-day (1980) flow system under stressed conditions brought about a somewhat different conceptual model of that flow system.

GEOGRAPHIC AND TOPOGRAPHIC SETTING

The study area lies entirely within the Coastal Plain and Continental Shelf provinces of the Atlantic Plain (Fenneman, 1938, pl. 3). The onshore Coastal Plain province accounts for about 20,000 mi^2 of the study area and the offshore Continental Shelf province, about 10,000 mi^2. Of the Coastal Plain province, about 75 percent of the area is within the Sea Island section, 16 percent within the East Gulf Coastal Plain section, and 9 percent within the Floridan section (fig. 2).

The topographic divisions shown in figure 3 are chiefly those of Cooke (in LaForge and others, 1925, p. 17, for Georgia; Cooke, 1936, p. 3, for South Carolina; and Cooke, 1939, p. 14, for Florida). Stringfield (1966, fig. 2) modified the divisions somewhat to conform along State lines.

The Coastal Lowlands range in altitude from sea level to about 100 ft. The region typically consists of barrier islands, marshes, level plains, and a series of five terraces resulting from the most recent advances and retreats of the sea during the late Pleistocene, which left shorelines and sea floors along the Coastal Lowlands.

The Central Highlands of Florida include all of north-central Florida inland of the Coastal Lowlands and range in altitude from about 40 to 250 ft in the study area. The Central Highlands area includes lakes, swampy plains, terraces, ridges, and hills. The central part of the Central Highlands is marked by karst topography—characterized by numerous sinks, sinkhole lakes, sinking streams, and springs—that extends into the Valdosta area of south Georgia. The karst topography in this area is a result of uplifting of the carbonate rocks during post-Oligocene time which locally exposed the rocks and facilitated erosion of the overburden (Stringfield, 1966, p. 73). This part of the study area, because of its karst features, is one of the most hydrologically dynamic areas, having large quantities of recharge through swallow holes, sinkholes, and sinkhole lakes, and discharge from springs.

The Coastal Terraces of Georgia and South Carolina range in altitude from about 100 to 270 ft. The area's topography is chiefly an inland continuation of the terraces deposited along the Coastal Lowlands and is represented by similar shorelines and sea bottoms left by early Pleistocene advances and retreats of the sea.

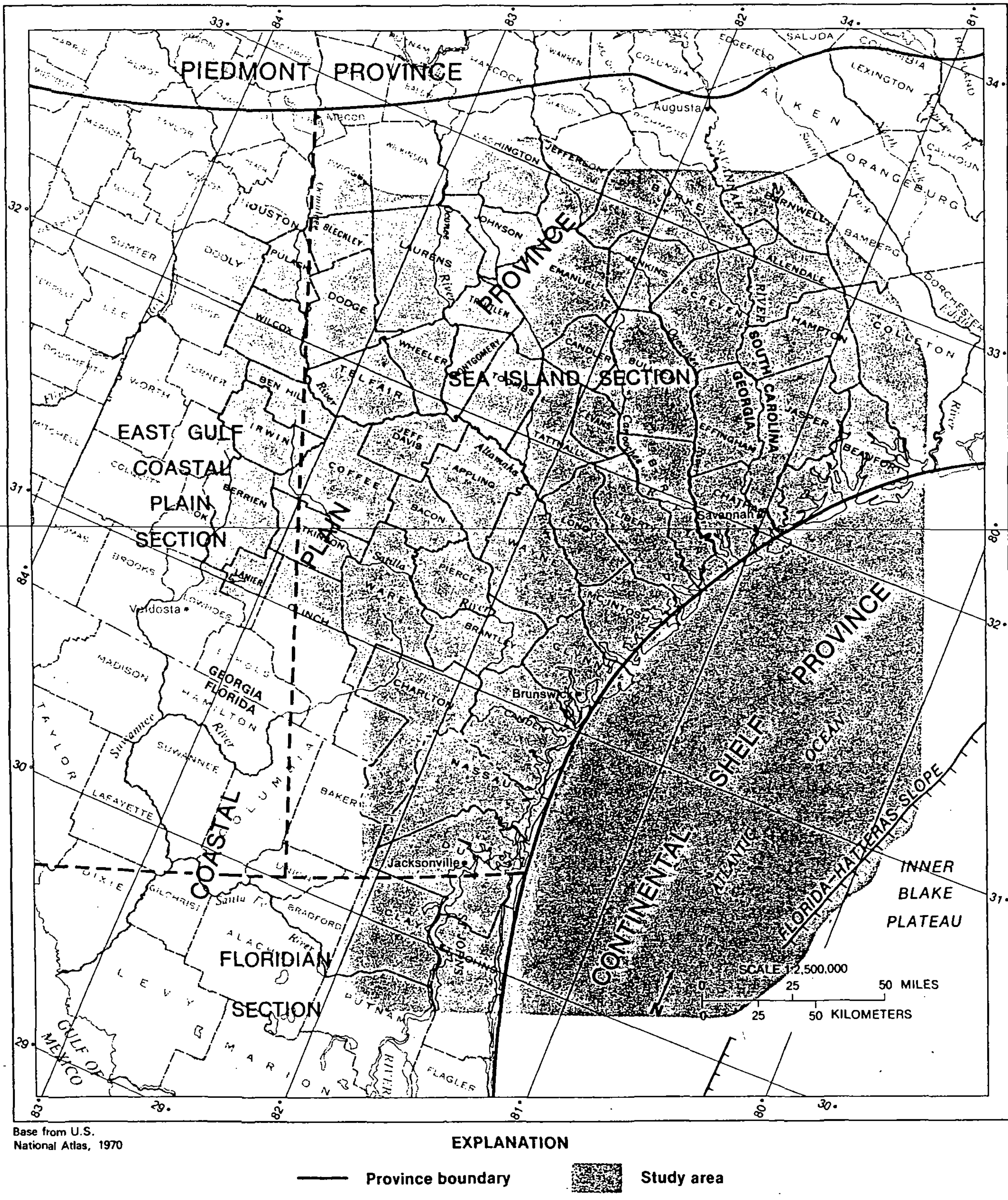
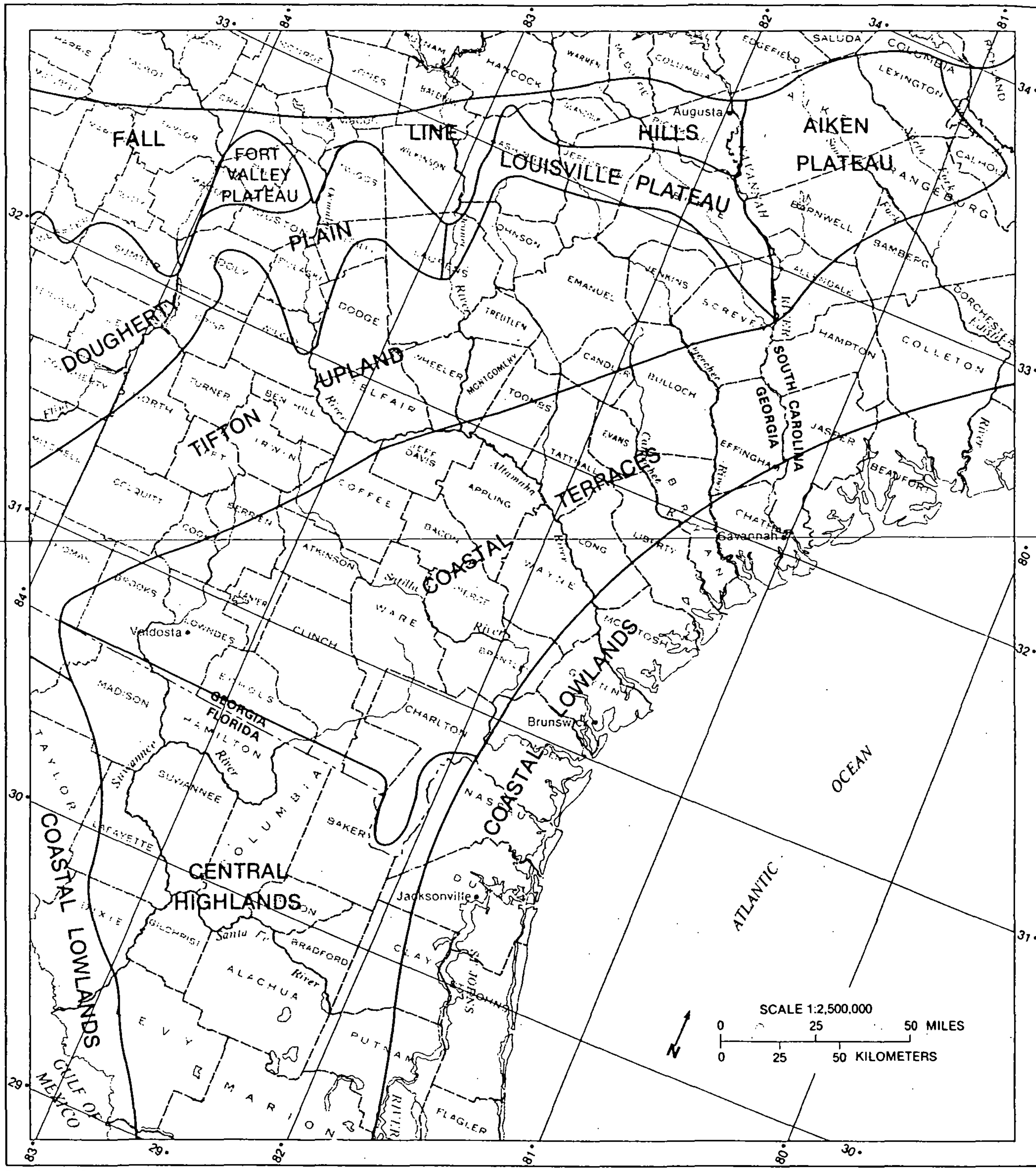


FIGURE 2.—Location of study area and physiographic subdivisions. From Fenneman (1938).



Base from U.S. National Atlas, 1970

FIGURE 3.—Generalized topographic divisions of the Coastal Plain province. From LaForge and others (1925), Cooke (1936; 1939), and Stringfield (1966).

The Tifton Upland ranges in altitude from about 120 to 400 ft in the study area and is characterized by rolling hills and both gentle and deeply incised valleys. The Hawthorn Formation of Miocene age (table 1) underlies the Tifton Upland and extends downdip toward the coast, becoming more deeply buried under the Coastal Terraces. The upland is terminated to the northwest by a scarp and to the southeast by the Coastal Terraces. The Coastal Terraces boundary of the Tifton Upland is the approximate downdip edge of the Gulf Trough, a series of clastic-filled basins formed by high-angle faults (D.C. Prowell, U.S. Geological Survey, written commun., March 1982; Miller, 1985). The trough is narrow, generally less than 5 mi wide but as much as 10 mi wide in central Georgia and near the Florida–Georgia State line. The trough has a pronounced effect on the hydrology of the aquifer system, as ground-water flow is impeded by the fine clastic material in the trough, and on water quality, as mineralized water is associated with evaporites downgradient from the trough.

The Dougherty Plain ranges in altitude from about 200 to about 600 ft in the study area. The Dougherty Plain is typical of a karst topography, especially in the southwestern part of Georgia where limestone is covered by only a thin residuum. The northwestern part of the plain is characterized by subtle hills and valleys. Here the Hawthorn Formation is missing and the aquifer grades into sands.

The Louisville Plateau and Fort Valley Plateau are similar to the northeastern part of the Dougherty Plain. The plateaus range in altitude from about 300 to 600 ft and are characterized by broad, flat uplands. The area of the Louisville Plateau is roughly the same as the areal extent of sand and calcareous sand (Barnwell Formation) that is equivalent in age to the Upper Floridan aquifer. The Fort Valley Plateau is also underlain by this sand.

The Aiken Plateau is similar to the Louisville Plateau, having about the same altitude range and being underlain by similar material. Undrained depressions and Carolina Bays are common in the Aiken and Louisville Plateaus.

The Fall Line Hills area ranges in altitude from about 300 to 800 ft and is characterized by rolling hills and valleys. The area corresponds roughly with the outcrop area of Cretaceous material that extends from the Piedmont province at the Fall Line to the plains and plateaus coastward.

GENERAL HYDROLOGY

PRECIPITATION

Average annual precipitation based on the records for 1941–70 ranges from less than 44 in/yr south of Augusta, Ga., to more than 58 in/yr in a small area west of Jacksonville, Fla. (fig. 4). Each area of extreme range is represented by only one climatological station. In most of the study area, the average annual precipitation ranges from 46 to 56 in/yr. Precipitation is generally lowest in the east-central part of the Coastal Plain of Georgia and along the South Carolina coast and greatest in northern Florida.

Rainfall is unevenly distributed throughout the year. Within the study area, maximum rainfall, mainly from thunderstorms, occurs during the summer months of July and August in most of Georgia and in South Carolina. Maximum rainfall occurs in June, July, and August in south Georgia, and in July, August, and September in northeast Florida. Minimum rainfall occurs during October and November over most of the area and extends through December in south Georgia and northeast Florida, and through January farther south in Florida. Seasonal variation is greater in the coastal area than inland.

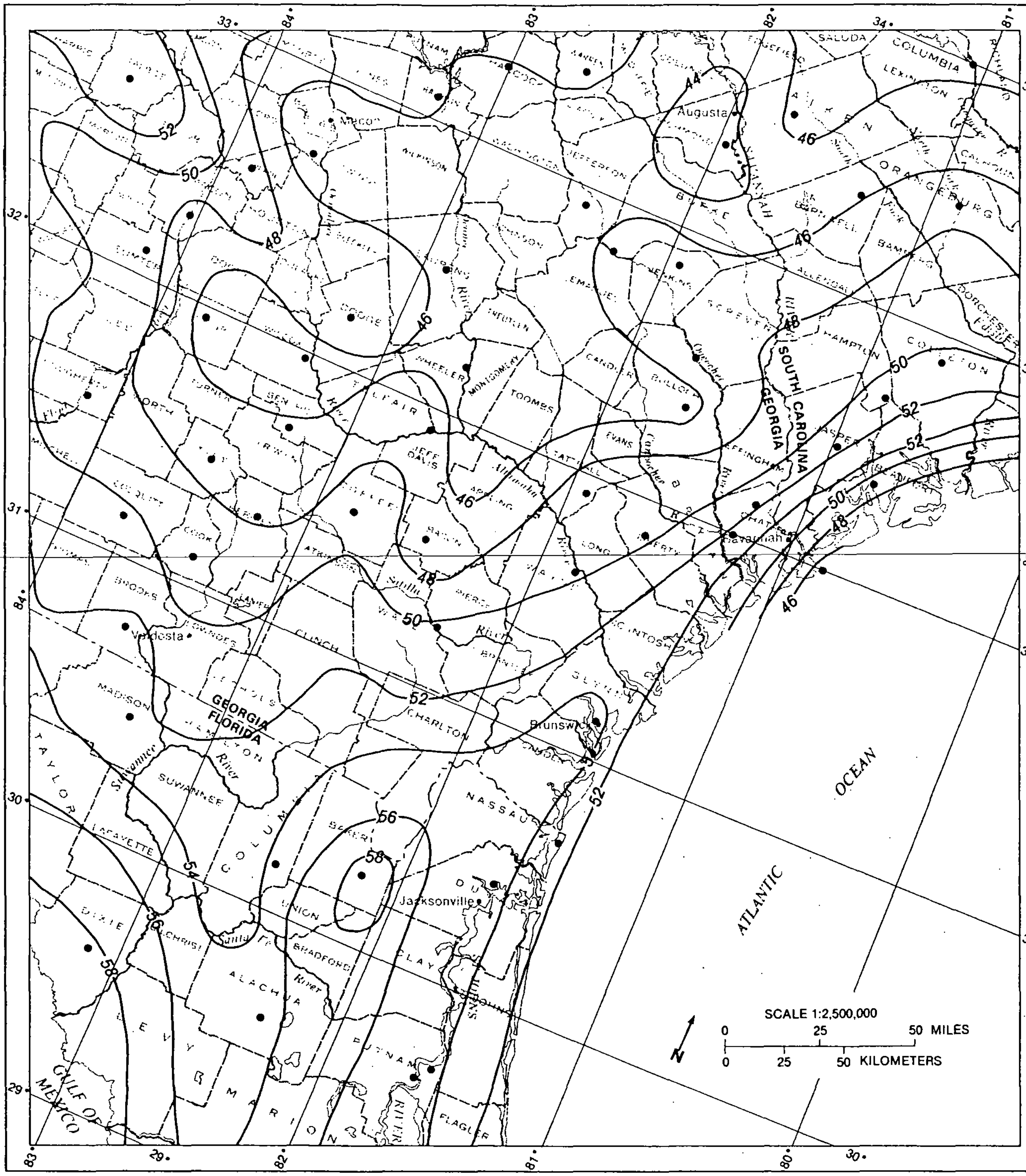
Rainfall as a source of recharge to aquifers is most important during the nongrowing season, when evapotranspiration is lowest. Generally, October through March constitutes the nongrowing season in the study area. During this period, average precipitation ranges from about 15 in/yr along the coast to almost 25 in/yr immediately below the Fall Line.

RUNOFF

Average annual runoff, based primarily on records for the period 1941–70, ranges from about 10 to 15 in/yr in most of the study area (fig. 5). Runoff is generally lowest along the coast and highest immediately below the Fall Line, corresponding to a similar distribution of precipitation.

Runoff is anomalously high in the Suwannee River basin, where average annual runoff for the period of record was greater than 35 in/yr. Rainfall is also high in this area (fig. 4), but the primary cause of the high runoff is interbasin transfer of water. In this area, water derived from rainfall in adjacent basins moves through the Floridan aquifer system and discharges as springs or seeps into the downgradient part of the Suwannee River basin. Conversely, the upgradient part of this basin loses significant quantities of water to sinking streams, thereby anomalously reducing runoff. Therefore, in the karst areas of north-central Florida and extreme south-central Georgia, basin runoff is not a simple function of the rainfall less evapotranspiration and infiltration, but also is related to karst topography.

Lines of equal runoff in figure 5 are drawn on the basis of average annual runoff at the centroid of the drainage area above the corresponding stream gages. Ad-



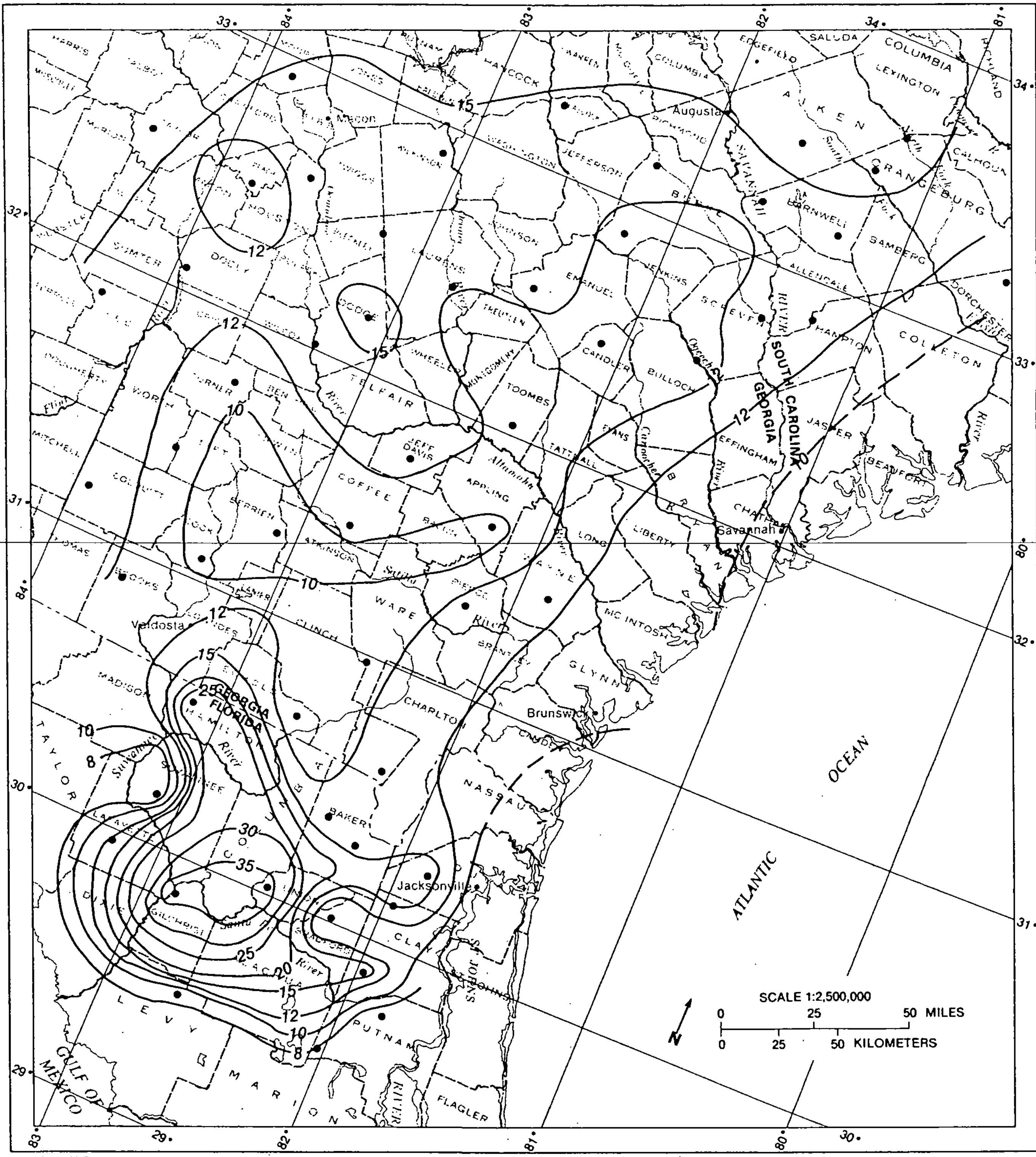
Base from U.S.
National Atlas, 1970

EXPLANATION

—52— **Line of equal precipitation**—Interval 2 inches

● **Data point**

FIGURE 4.—Average annual precipitation, 1941–70.



EXPLANATION

—10— Line of equal runoff—Interval 2 inches below 12, 3 inches to 15, and 5 inches above 15. Dashed where approximately located

• Data point

FIGURE 5.—Average annual runoff, 1941–70.

justments were made to discharge at gages where diversions, regulations, or consumptive uses were significant. Data were omitted for sites where satisfactory adjustments could not be made. Data for the period 1941–70 were used except for a few sites in South Carolina and Florida, where the only data available were for periods of record: from the forties or early fifties through 1978. Comparison of runoff at several nearby sites for all periods indicated an acceptable correlation. The period 1941–70, rather than the period 1951–80 (both conforming to the 30-year climatological summary period used by the U.S. National Weather Service), was used because more stream-discharge data from gaging stations were available in the earlier period, as several stations were discontinued between 1970 and 1980.

The average annual runoff for Florida shown in figure 5 may differ from that delineated for Florida by Hughes (1978) for several reasons: (1) the method of determining runoff herein, and depicting it with lines of equal runoff, is unlike the method used by Hughes, who merely showed ranges of runoff within major basin boundaries, and (2) data coverage for the method used herein was considerably greater; data from several subbasins, each having a unique runoff, were included herein, but were averaged and lumped into the larger hydrologic units of Hughes.

EVAPOTRANSPIRATION

Evapotranspiration ranges from about 30 to 40 in/yr over the study area (fig. 6). Areal distribution of evapotranspiration rates indicates that evapotranspiration increases from north to south and from inland toward the coast. An exception occurs in southeast Georgia, where the Okefenokee Swamp accounts for the highest rate of evapotranspiration in the State.

Evapotranspiration rates used to construct figure 6 were chiefly those determined by Bush (1982), who used the values to make initial estimates of recharge and discharge rates for the regional flow model. The lines of equal evapotranspiration rates shown in figure 6 were based on 25 data stations located at the centroids of areas that were subdivided on the basis of drainage area and Thiessen polygons of rainfall distribution. Bush (1982) estimated total evapotranspiration rates within each basin from weighted averages of evaporation rates from open-water areas, such as swamps and marshes, and evapotranspiration rates from land areas. He estimated open-water evaporation rates from a map of average annual lake evaporation for the period 1946–55 (Kohler and others, 1959, pl. 2). Evaporation rates from swamp and marsh areas were assumed to be 90 percent of the open-water rate (Bush, 1982).

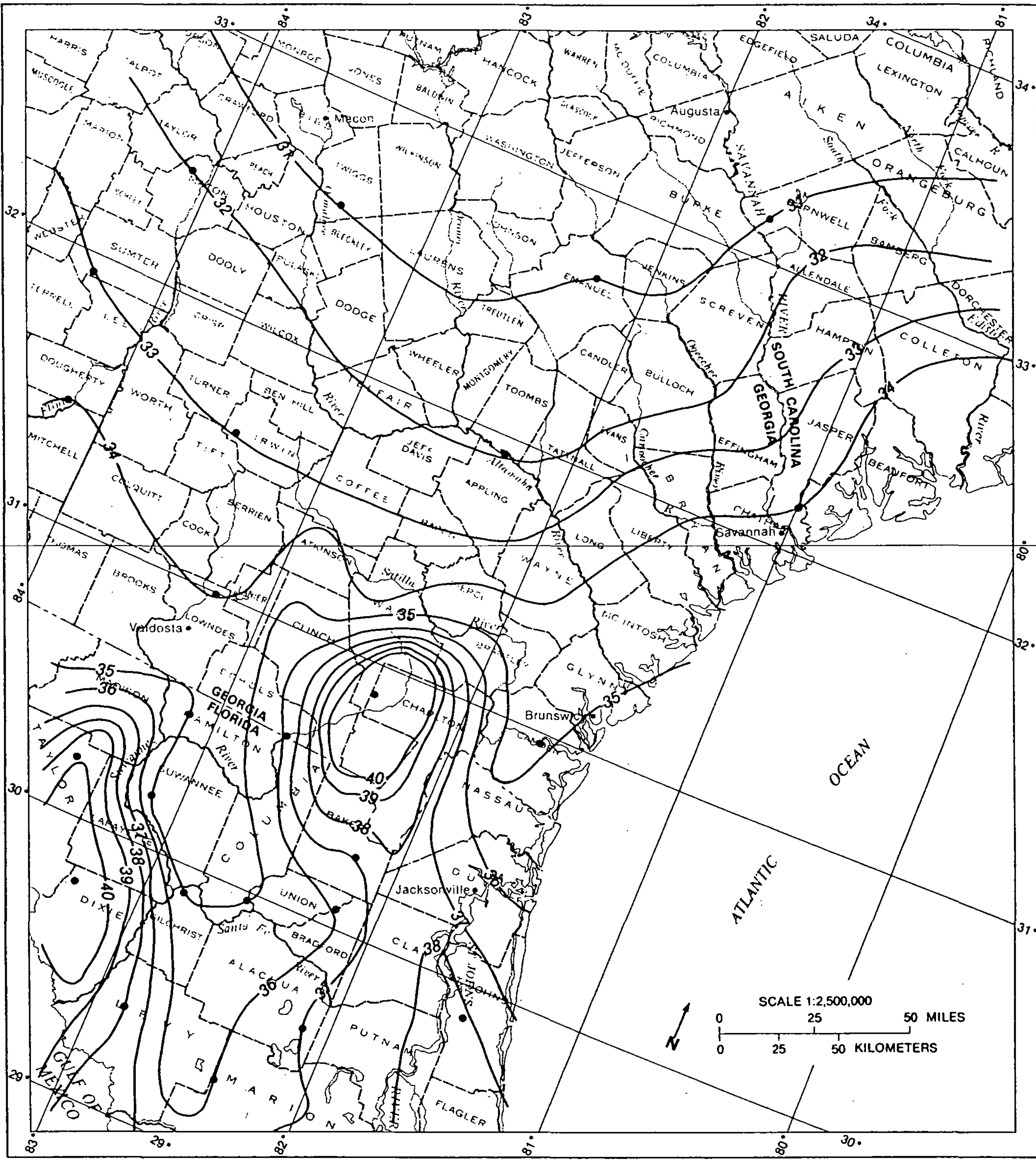
Bush (1982) estimated rates of evapotranspiration from land areas by using a method developed by Holdridge (1967) and later described and used in Florida by Dohrenwend (1977, p. 185). The method uses Holdridge's (1967) "life-zone" bioclimatic classification system, based on latitudinal and altitudinal regions, humidity provinces, soil and vegetative types, and precipitation. The important variable in the method is biotemperature, defined by Holdridge (1967) as the sum of hourly temperatures between 0° and 30°C divided by the number of hours in the year. For a complete discussion of the methodology, see Bush (1982).

HYDROGEOLOGIC SETTING

In general, the Floridan aquifer system is made up of consolidated marine and marginal marine limestone and dolomite and lesser amounts of evaporites, clay, sand, and marl (table 2, in pocket). In the study area, the aquifer system consists of several formations that range in age from early Eocene to Oligocene (table 2). Principal units making up the system are the Oldsmar and Avon Park Formations and the Ocala, Santee, and Suwannee Limestones. Locally, in the Brunswick, Ga., area, rocks of Paleocene age (the Cedar Keys Formation) and the Lawson Limestone of Late Cretaceous age are also part of the aquifer system. In the northern part of the study area, updip clastic facies of the carbonates, although not considered by Miller (1985) to be part of the Floridan aquifer system, are hydraulically connected with it and are thus part of its regional flow system. The aquifer system forms a nearly vertically continuous carbonate sequence that is hydraulically connected in varying degrees. Zones of low permeability and areal continuity exist within the Floridan throughout most of the area and separate the aquifer system into two permeable, water-bearing zones, the Upper Floridan aquifer and the Lower Floridan aquifer, and locally into a third zone, the Fernandina permeable zone, which is part of the Lower Floridan aquifer. The Floridan is confined below by low-permeablity beds of clastic or evaporitic material, and in most of the area is confined above by clayey strata primarily of Miocene age (table 2).

HYDROGEOLOGIC FRAMEWORK OF THE FLORIDAN AQUIFER SYSTEM

The hydrogeologic framework of the Floridan aquifer system in southeast Georgia and parts of Florida and South Carolina described in this report chiefly follows the regional definition of the aquifer system described by Miller (1982a, b, c, d, e; 1985, chapter B of this Professional Paper series). Miller's framework of the aquifer system is restricted to the predominantly carbonate sequence. However, the hydrogeologic framework described herein also includes updip, largely clastic beds



Base from U.S. National Atlas, 1970

EXPLANATION

—37— **Line of equal evapotranspiration**—Interval 1 inch

• **Data point**

FIGURE 6.—Average annual evapotranspiration. Adapted from Bush (1982).

that are chronostratigraphic equivalents of the carbonate sequence and can be shown by simulation to be part of the Floridan's flow system.

The Floridan aquifer system thickens from a featheredge in the northern outcrop area to more than 2,000 ft downdip in coastal Georgia and to more than 2,600 ft locally in the area of Brunswick, Ga. (pl. 1). The system includes all strata that lie between the top of the uppermost continuous high-permeability carbonate sequence (top of the Floridan) and the top of highly clastic or evaporitic rocks having low permeability (base of the Floridan).

Plate 1 and the other hydrogeologic framework maps in this report are modified from Miller (1982a, b, c, d, e). Miller mapped the areal extent of the top, base, and thickness of the aquifer system and separated the component aquifers and confining units on the basis of permeability contrasts. These permeability contrasts may exist anywhere within a rock unit (stratigraphic horizon or stage equivalent). Therefore, these maps may differ from previously published maps that portray the extent of carbonate sequences or particular geologic units that are not classified on the basis of permeability contrast.

Various geologic and time-stratigraphic units in different combinations make up the aquifer system in different places. The thickness of the aquifer system is represented by the composite thickness of several units having similar permeability characteristics, yet the number of units that make up the system, and their ages, may differ from place to place.

Miller (1982d) arbitrarily placed the updip limit of the aquifer system along a line where the aquifer system is generally less than 100 ft thick and where clastic units, which are facies of the limestone units, make up more than 50 percent of the section. In the updip part of the aquifer system, limestone becomes a small part of the section, being interbedded with calcareous sand and clay. Still farther updip, these units grade into units that are mostly clastic, are stratigraphic equivalents of the limestone, and have hydrologic properties somewhat similar to the limestone. In this updip area north and west of the line shown on plate 1 as the approximate updip limit of the aquifer system, there are thin beds and lenses of limestone that may be either connected to the main limestone body or isolated from it because of postdepositional erosion. Although these thin beds locally yield small to moderate amounts of water, they are not considered part of the Floridan aquifer system of Miller (1985). However, the thin limestone units and the clastic units in this updip area are included in the flow simulation in this study because of their local hydrologic significance.

Generally, in northeast Florida and southeast Georgia, rocks of the aquifer system consist of limestone and dolomite, having very little organic or argillaceous material (Chen, 1965, p. 75). In the northern part of the study area, the rocks of the lower part of the aquifer system are terrigenous clastics. In a northerly direction from a line trending east-northeast through Echols County, Ga., the limestone and dolomite become more argillaceous, then arenaceous, grading to calcareous clastics and finally to noncalcareous clastics at the outcrop belt along the Fall Line. The transition zone between the carbonate and clastic facies is the approximate northern extent of the thick carbonate platform that existed in the Florida peninsula during early Tertiary time. Between the predominantly terrigenous clastic and the predominantly carbonate areas and trending east-northeast through Echols County, Ga., is a thick sequence of Tertiary material, chiefly fine calcareous clastics and carbonates, that probably represents the Suwannee Strait described by Ewing and others (1966, p. 1969) and Husted (1972, p. 1558) or the Suwannee Channel described by Chen (1965, p. 10). The channel or strait was a factor influencing the distribution of these depositional facies. The effect of the channel or strait was most pronounced in Late Cretaceous time, and its effect decreased with time until it finally disappeared near the end of Eocene time. The transition zone between carbonate facies to the south and clastic facies to the north migrated northward from extreme southeast Georgia during Paleocene and Eocene time (Chen, 1965, p. 8, 9). The carbonate platform subsequently enlarged toward the north until finally, in late Eocene time, the carbonate facies had extended to a line approximated by the 100-foot aquifer-system thickness line (pl. 1).

The central part of the coastal area of Georgia, where the aquifer system is thick (pl. 1), lies in a depositional basin called the Southeast Georgia embayment. The altitude of basement rock is lower and all time-stratigraphic units in the Tertiary System are thicker in the embayment than in surrounding areas. Within this embayment, in the area of Brunswick, Ga., rocks of Paleocene and Late Cretaceous age are part of the Floridan aquifer system, resulting in a great thickness of the system in that area.

A significant feature affecting the thickness of the aquifer system is the Gulf Trough, first defined by Herrick and Vorhis (1963, p. 55) and later described by Gelbaum (1978, p. 39). The Gulf Trough trends northeastward within the study area from Colquitt County to Effingham County, Ga., and extends southwestward out of the study area to the panhandle of Florida. Simulation of the flow system indicates that the trough probably extends northeastward into South Carolina.

The Gulf Trough is a graben system caused by high-angle faulting that was active during much of the time of deposition of the rocks that make up the Floridan aquifer system (Gelbaum, 1978). Within the grabens are thick accumulations of low-permeability, clastic sediments and argillaceous carbonate rocks. Permeable, water-bearing units of the aquifer system are thus thinner within these grabens. (See pl. 1.)

Ground-water flow in the Floridan aquifer system is partially impeded by the Gulf Trough as a result of two mechanisms. First, near-vertical displacement of rocks along the faults of the graben system has juxtaposed rocks of lower permeability against the more permeable rocks of the aquifer system. Second, within the grabens the aquifer system consists of relatively low permeability material, which decreases the aquifer system's effective thickness.

Immediately downdip from the Gulf Trough, in the western part of the study area, the aquifer system is thin, ranging in thickness from about 400 to 900 ft (pl. 1). In this area the limestone of the lower part of the aquifer system contains evaporites, chiefly gypsum, that occur as nodules and lenses infilling the otherwise porous limestone (Krause, 1979). In this area, ground-water flow downgradient from the Gulf Trough was restricted and probably was not sufficient to produce the secondary porosity and permeability of the aquifer system as in other parts of the study area.

The limestone making up the Floridan aquifer system is thin in part of South Carolina, ranging in thickness from about 20 to 80 ft (pl. 1). In this area, the Upper Floridan aquifer is largely absent (Hayes, 1979, p. 28–30) and the Lower Floridan makes up the aquifer system. In a northeasterly direction from the extreme southern part of South Carolina, the Upper Floridan aquifer becomes thin and undergoes a facies change to low-permeability clastic rocks; the effect is that of a pinch-out of the Upper Floridan (Miller, 1985). Also, nearly all wells drilled in this part of South Carolina for water supply pass through the Upper Floridan and tap the Lower Floridan, where water is readily available. The northeasterly extent of the Upper Floridan (pl. 1) is marked arbitrarily by the reduction of the aquifer system's permeability and is shown on plate 1 by a dashed northwest-trending line whose location is based on widely scattered well control. In this area, the Lower Floridan aquifer consists of a thin permeable section at the base of the middle Eocene Santee Limestone.

An indication that the middle Eocene Santee Limestone is a significant aquifer in Orangeburg County, S.C., northeast of the Floridan aquifer system's extent as defined by this study, is documented by Siple (1975, p. 30). Siple (1975, p. 36) states that the Santee is the lithostratigraphic equivalent of the "Principal Limestone Aquifer" of Stringfield (1966, p. 95), which is basically equivalent to the Floridan aquifer system herein described. Siple (1975, p. 30, 36, 37) also states that the Santee is permeable and locally karstic, containing caves and springs near Lake Marion (located along the eastern county lines of Calhoun and Orangeburg Counties) and having transmissivity (estimated from specific-capacity data) as high as 5,000 ft^2/d. One well tapping the Santee was reportedly pumped at a rate of 600 gal/min with no appreciable drawdown (Siple, 1975, p. 40). In Colleton County, between the Orangeburg County area and the limit of the Floridan aquifer system defined in this report, Hayes (1979, p. 38–42) considers the upper permeable zone (Upper Floridan) to be thin and of low yield (less than 250 gal/min with more than 25 ft of drawdown). The lower permeable zone of Hayes (1979), equivalent to the Lower Floridan aquifer of this report, also yields small quantities of water. The specific capacities of eight wells tapping the Floridan aquifer system in Colleton County (Hayes, 1979, table 10) are less than 5 (gal/min)/ft. Thus, although rocks of the Santee Limestone in Orangeburg County northeast of the study area are probably stratigraphically equivalent to the Floridan aquifer system of the study area, and constitute a significant aquifer in both areas, they are not continuous and the Floridan probably extends only to its limit delineated in this study (pls. 1–4).

TOP OF THE AQUIFER SYSTEM

The top of the aquifer system as defined and mapped by Miller (1982d) represents the top of the highly permeable carbonate rock that is overlain by low-permeability material, either clastic or carbonate, which makes up the upper confining unit. Rocks of Oligocene age (Suwannee Limestone or equivalent) make up the top of the aquifer system over most of the central part of the study area. Rocks of late Eocene age represent the top of the aquifer system in most of northeast Florida and extreme southeast Georgia, and in small areas of Georgia and adjacent South Carolina where the Oligocene rocks have been stripped away by post-Oligocene erosion. Locally, in northeast Florida, small outliers of Oligocene rocks that were not eroded constitute the top of the aquifer system. Rocks of late Eocene age also make up the top of the aquifer system in east-central Georgia and adjacent South Carolina (pl. 2). Here, Oligocene rocks were not deposited, or were thin and readily eroded, or both. In part of the extreme updip Coastal Plain in Georgia and South Carolina,

calcareous clastic rocks of late Eocene age make up the top of the aquifer system (pl. 2). Here, the rocks consist of fossiliferous, argillaceous, glauconitic, calcareous clay and are part of the Barnwell Formation. Hydraulically, these beds, which are clastic facies of downdip carbonate rocks, do not represent a significant, corresponding change in permeability. Instead, these permeable clastic beds are hydraulically connected with the downdip carbonate rocks of the Upper Floridan aquifer.

In the extreme northeast part of the study area in South Carolina, the lower part of the Santee Limestone of middle Eocene age forms the top of the aquifer system (pl. 2). The Lower Floridan constitutes the permeable part of the aquifer system here.

BASE OF THE AQUIFER SYSTEM

In general, the base of the aquifer system is youngest in the updip part of the study area and is successively older downdip. The base of the aquifer system is oldest in the area of Brunswick, Ga., where it consists of evaporite beds and low-permeability dolomite of Late Cretaceous age. The altitude, configuration, and stratigraphy of the base of the aquifer system, chiefly as defined by Miller (1985), are shown on plate 3. In places, the base of the flow system differs slightly from the hydrogeologic base of the aquifer system as defined by Miller (1985). The predominantly clastic units, which lie both updip and below the predominantly carbonate rocks, are not a part of the Floridan aquifer system as defined by Miller (1985). They are hydraulically connected with the aquifer system, however, and thus were simulated during this study.

Rocks primarily of late Eocene age form the base of the aquifer system in the area downdip from the Gulf Trough in the western part of the study area (pl. 3). There, deposition of secondary gypsum has filled most of the pore space in the lower part of the Ocala Limestone and locally in the upper part of the Avon Park Formation. The Ocala is normally a highly permeable rock unit, and is the most productive of any of the formations in the Floridan aquifer system in the study area. Owing to the gypsum mineralization and the general lack of high secondary permeability, the lower part of the Ocala is a low-permeability unit to the southeast of the western part of the Gulf Trough within the study area. In that part of the area, the Ocala grades downward into low-permeability clastic rocks of the Lisbon Formation, and no Lower Floridan aquifer is present.

The base of the aquifer system near its updip limit in the northwestern part of the study area (pl. 3) is composed of fine-grained, calcareous, glauconitic sand interbedded with clay and argillaceous sand. These strata are part of the Lisbon Formation of middle Eocene age. Still farther downdip, the thickness of permeable material in the aquifer system increases and its base becomes progressively lower toward the southeast with respect to altitude and stratigraphic position. In a narrow northeast-trending strip across the central Georgia Coastal Plain, clastic rocks of the Lisbon Formation have graded by facies change into permeable limestone, which continues downdip. The base of the aquifer system in this transition zone consists of fine-grained, highly glauconitic sand, argillaceous sand, and clay, all of which are part of the Tallahatta Formation (pl. 3).

In the area along the Savannah River in Georgia and South Carolina (pl. 3), the base of the aquifer system is composed of highly sandy, calcareous clay interbedded with soft, sandy, argillaceous limestone and fine, calcareous sand. These rocks are time-equivalent to the Santee Limestone of South Carolina. Both the updip Lisbon and the downdip Tallahatta grade laterally into the Santee equivalent by facies change.

In these aforementioned areas where the base of the aquifer system is composed of middle Eocene rocks, permeable clastic units lying below the predominantly carbonate rocks are not a part of the aquifer system of Miller (1985) and are thus not shown on plate 3. They are, however, hydraulically connected with the downdip and the overlying carbonate facies of the Lower Floridan. Where such sands are present, the base of the Floridan aquifer system, for purposes of this study, lies within the Huber Formation in updip areas, and within either the Gosport equivalent, the Lisbon Formation, or the Tallahatta Formation in downdip areas.

Clastic rocks of early Eocene age form the base of the aquifer system in east-central coastal Georgia. These low-permeability rocks consist of silty, highly glauconitic, micaceous fine sand interbedded with lignitic clay. They are undifferentiated at present, but they are stratigraphic equivalents of the Tuscahoma and Nanafalia Formations of western Georgia and eastern Alabama. In the northern part of this area, permeable, clastic material of early Eocene age is hydraulically connected with the carbonate facies of the Lower Floridan.

The base of the aquifer system in south-central Georgia and adjacent counties in north Florida is represented by chalky, glauconitic, gypsiferous limestone and dolomite that are part of the Oldsmar Formation. Part of the Oldsmar grades northward and westward into equivalents of the Tuscahoma and Nanafalia Formations.

The Cedar Keys Formation of Paleocene age constitutes the base of the aquifer system in northeast Florida and extreme southeast Georgia. Rocks of the Cedar Keys Formation are dolomitic limestone and dolomite, having regionally extensive interbedded anhydrite layers that mark the base of the system. In

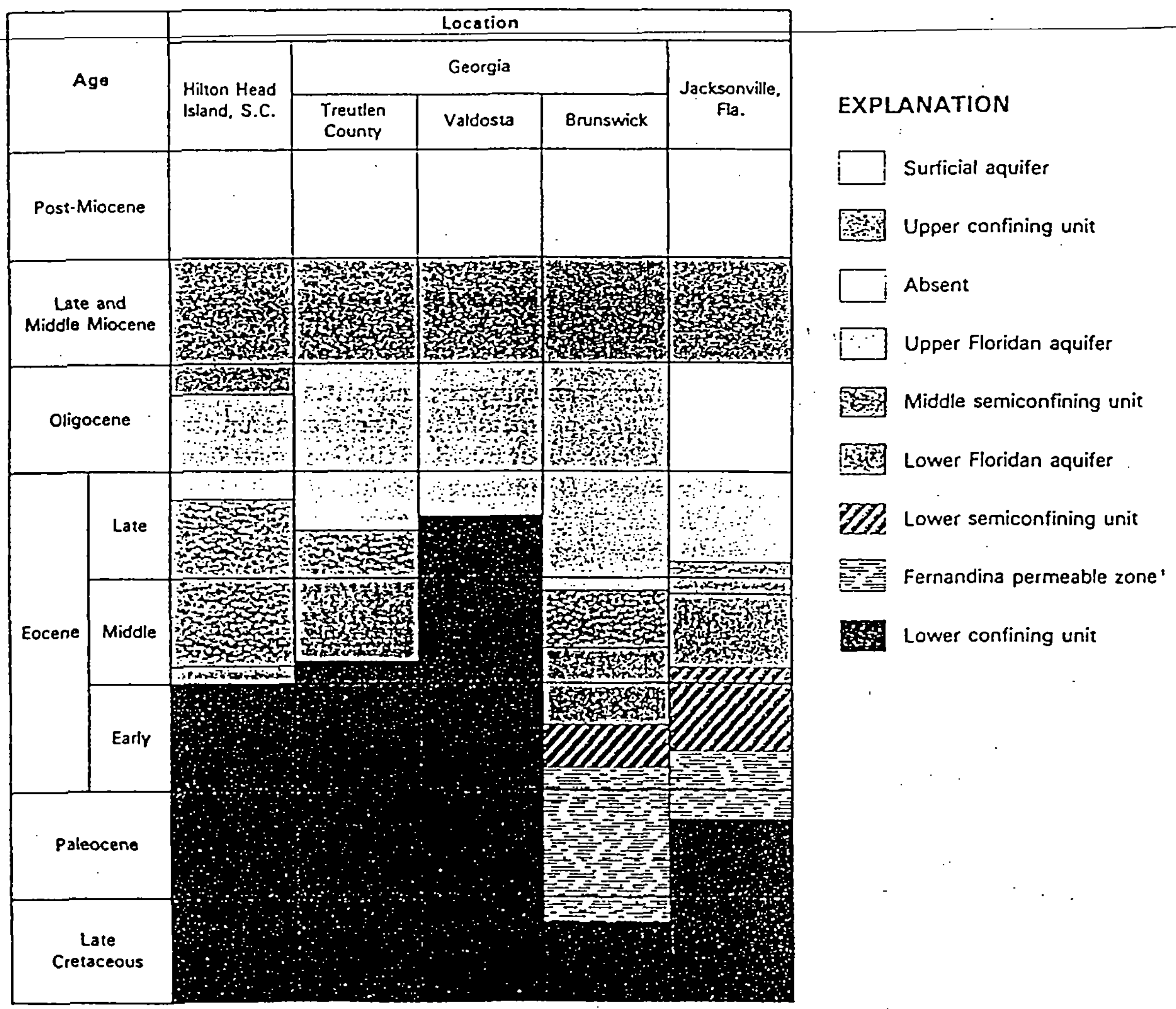
the extreme northeast part of the study area in South Carolina, the base consists of fine-grained, argillaceous, calcareous sand of the Black Mingo Formation.

Locally, in the area of Brunswick, Ga., the base of the aquifer system consists of soft, argillaceous, chalky limestone of Late Cretaceous (probably Tayloran) age. Younger, highly permeable, Late Cretaceous (Navarroan) calcarenite overlies the chalk and is part of the aquifer system.

AQUIFER-SYSTEM LAYERING

The Floridan aquifer system can generally be divided into upper and lower major permeable zones, called the Upper Floridan and the Lower Floridan aquifers, respectively. These aquifers are separated by what is termed the "middle semiconfining unit," whose age and lithologic character vary. In part of the study area, there is an extensive high-permeability zone within the Lower Floridan aquifer, herein formally designated the "Fernandina permeable zone" (pl. 3). The Fernandina permeable zone is everywhere overlain by a low-permeability confining unit of subregional extent. Although this confining unit is known to leak along local fractures, it otherwise effectively separates the Fernandina permeable zone from the overlying permeable beds within the rest of the Lower Floridan aquifer. Throughout most of the study area, the Floridan aquifer system is confined above by low-permeability clastic rocks of Miocene age. The system is everywhere underlain by a lower confining unit, which consists of low-permeability materials that may be evaporites, clastic rocks, or carbonate rocks. The age of the lower confining unit ranges from late Eocene to Late Cretaceous. (See table 3 and pl. 3.) The individual

TABLE 3.—*Aquifer-system layering*



¹ Part of Lower Floridan aquifer.

aquifers and confining units are shown on plates 4 and 5 and described below.

SURFICIAL AQUIFER

In most of the area where the Floridan aquifer system is confined, a surficial aquifer overlies the upper confining unit. The surficial aquifer consists of post-Miocene age, unconsolidated fine to very coarse, well-sorted sand, at depth commonly phosphatic and calcareous. In some areas, grain size is as large as fine gravel. Interbedded with these beds are layers of poorly sorted sand, clayey silt and sand, and, at depth, argillaceous limestone. In the extreme updip part of the study area, the upper confining unit is absent and the calcareous, clastic facies of the Floridan are largely unconfined. In this area, the Upper Floridan is under water-table conditions and supplants the surficial aquifer.

Water in the surficial aquifer is unconfined or under water-table conditions. The configuration of the water table is generally a subdued replica of the land surface. The water table is near land surface in low-lying areas, along streams, in marshes and swamps, and generally in areas along the coast. The water table also is near land surface in areas where the aquifer contains beds of low-permeability material. Generally, the water table is lower beneath topographic highs in areas of moderate to comparatively high relief. It is also lower where thick deposits of permeable material are present, such as along the Pleistocene shoreline ridges paralleling the coast. Relatively steep gradients in the water table adjoin the major stream courses, and relatively gentle gradients exist in the broad interstream areas.

In some areas where the clastic material overlying the Floridan aquifer system is thick, such as in the Southeast Georgia embayment, additional, partially confined permeable zones of clastic material are present within the upper confining unit and between the surficial aquifer and the Upper Floridan. Heads in these water-bearing zones may be higher or lower than heads in the surficial aquifer, depending on the degree of confinement, proximity of aquifers, withdrawal of water from the aquifers, and head gradient between the surficial aquifer and the Upper Floridan aquifer.

Precipitation infiltrates the surficial aquifer and moves down to the water table, providing the prime source of recharge to the aquifer. Water moves laterally downgradient and discharges into streams, ponds, and other surface-water bodies. Some water is lost to evaporation and transpiration, and some leaks downward into the Upper Floridan. The water level in the surficial aquifer responds rapidly to rainfall and shows seasonal variations corresponding to similar variations in rainfall and evapotranspiration. Seasonal fluctuations in the water level may be as great as 15 to 20 ft in areas of high topographic relief and where the aquifer is composed chiefly of coarse clastic, high-permeability material. Seasonal fluctuations are more commonly less than 10 ft in flat-lying areas and where low-permeability material is within, and especially near the top of, the surficial aquifer (fig. 7). Long-term climatic fluctuations in the water level in the surficial aquifer are probably negligible. Marked departures from normal precipitation (based on the period 1943–81) typically cause only a few feet of change in the water level (fig. 8).

The surficial aquifer functions as a source or sink to the underlying Floridan aquifer system, receiving water from or giving water to the Floridan. In areas where the water table in the surficial aquifer is above the potentiometric surface of the Floridan, the surficial aquifer recharges the Floridan by downward leakage through the upper confining unit. Where the head gradient between the surficial aquifer and the Floridan is in the opposite direction, the surficial aquifer receives upward leakage from the Floridan.

UPPER CONFINING UNIT

The upper confining unit consists primarily of the Hawthorn Formation of late and middle Miocene age, where present. It is composed of all strata between the surficial aquifer and the Upper Floridan aquifer, and thus includes not only clay of extremely low permeability but also, locally, sand beds of moderate permeability. In some areas, low-permeability beds of post-Miocene age are part of the upper confining unit. Over most of the study area, the unit is of middle Miocene age and consists of interbedded, locally highly phosphatic sand, silt, clay, and sandy clay beds of low permeability. The maximum thickness of the unit is about 600 ft in the Southeast Georgia embayment near Brunswick, Ga. (pl. 4).

The upper confining unit overlies all of the Floridan aquifer system except in the extreme updip part of the study area and in small areas where the confining unit has been breached or removed by erosion (pl. 4). These areas are not completely delineated by the lines of thickness of the upper confining unit shown on plate 4 because of the low density of control-well data. The thickness of the confining unit in the area of Brooks and Lowndes Counties, Ga., shown on plate 4 has been depicted with somewhat greater detail on the basis of work by Krause (1979, pl. 1). In Lowndes County, within the channel of the Withlacoochee River, the confining unit has been stripped away (pl. 4). In addition, some of the deeper sinkholes in the areas of thin confinement in the area of Lowndes County, as well as in the area of Keystone Heights, Fla., probably also breach the confining unit.

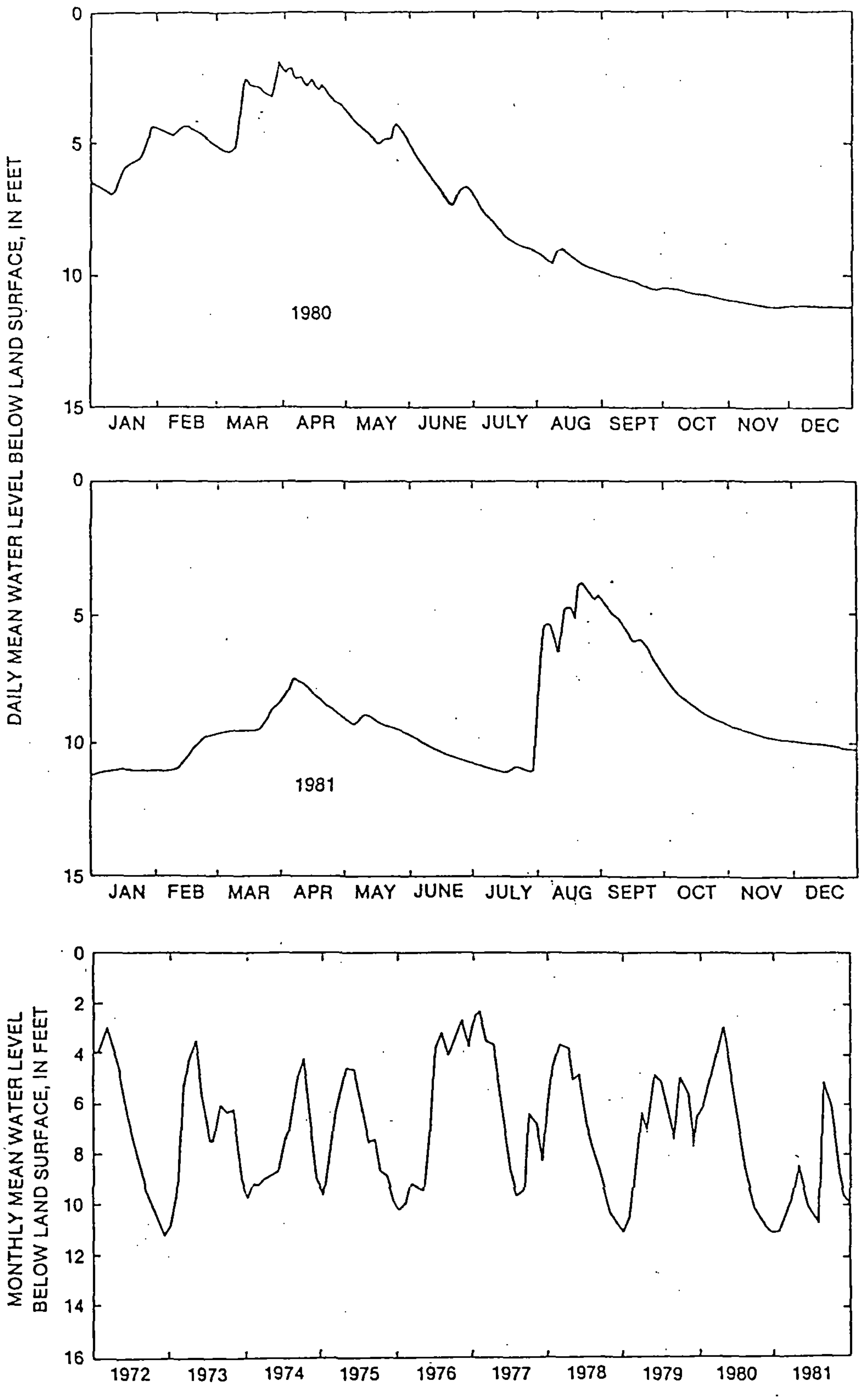


FIGURE 7.—Water-level fluctuations in the surficial aquifer, well 35P94, near Savannah, Ga.

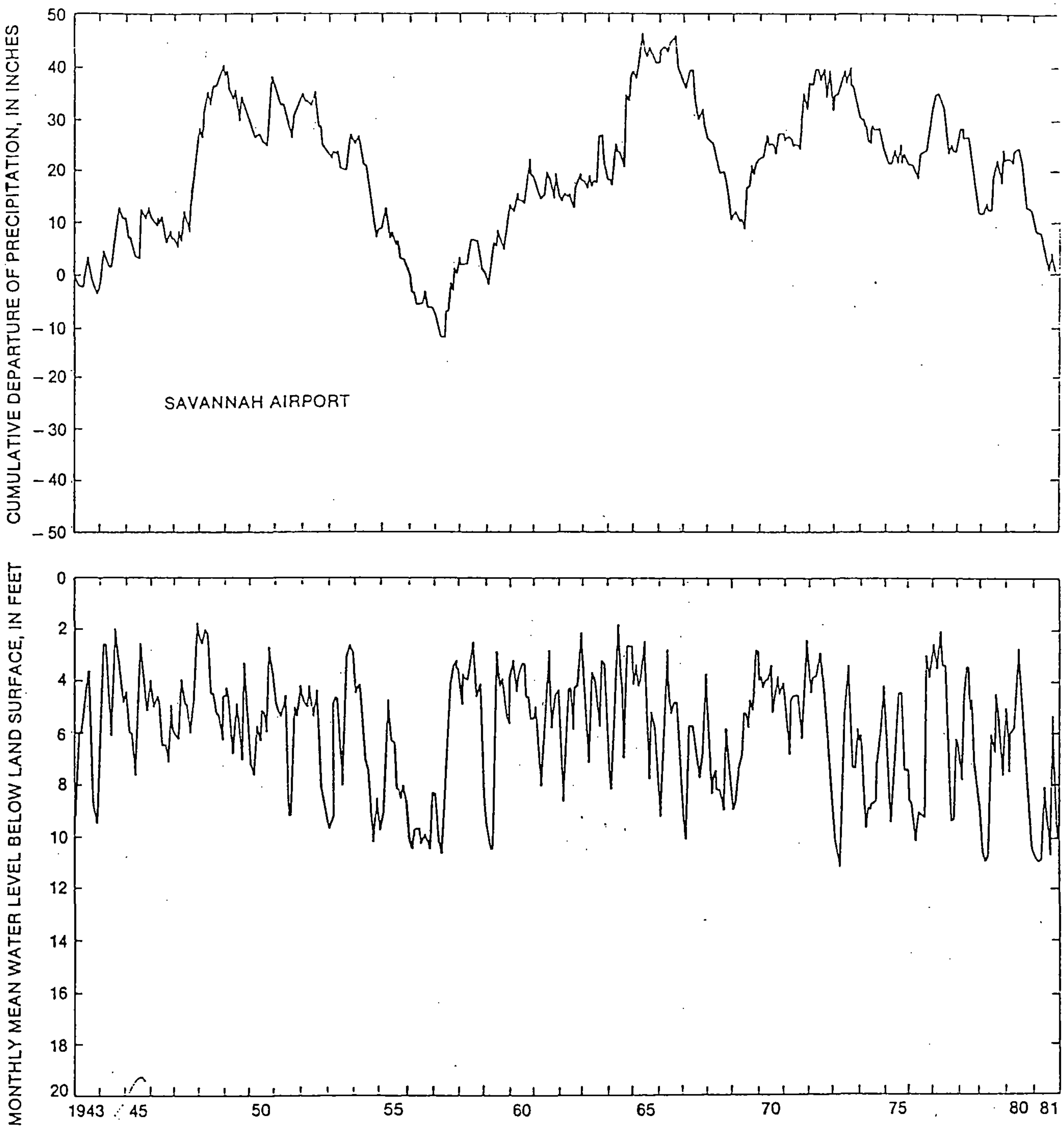


FIGURE 8.—Water-level fluctuations in the surficial aquifer, well 35P94, and cumulative departure of precipitation, Savannah, Ga., area, 1943–81.

In the area of Savannah, Ga., and Hilton Head Island, S.C., where the upper confining unit is thin, scouring action of creeks and estuaries, as well as the additional removal of material by dredging, has breached the upper confining unit (pl. 4) (Duncan, 1972, p. 103; Hayes, 1979, p. 30, 50; Randolph and Krause, 1984, p. 5).

In the part of South Carolina where the Upper Floridan aquifer is absent, the upper confining unit is mapped as an extension of the same late and middle Miocene and part of Oligocene strata that elsewhere compose the upper confining unit. Therefore, the thickness of the upper confining unit shown on plate 4 does not represent the entire thickness of the material overlying the Lower Floridan, but includes only the rocks that are chronostratigraphic equivalents of the upper confining unit.

The major updip rivers—Ocmulgee, Oconee, and Ogeechee in Georgia, the Savannah on the Georgia-South Carolina State line, and the Salkehatchee in South Carolina—also probably breach the confining unit, but the extent is largely unknown.

UPPER FLORIDAN AQUIFER

The Upper Floridan aquifer of the Floridan aquifer system consists chiefly of the Ocala Limestone and equivalents of late Eocene age. The Ocala, especially the upper part, is a very fossiliferous limestone having high effective porosity and permeability. Secondary permeability, which was developed by the migration of ground water along bedding planes, joints, fractures, and other zones of weakness, has made the Ocala extremely permeable.

In the area of Brunswick, Ga., the Upper Floridan consists of two permeable zones—the "upper and lower water-bearing zones" described by Wait and Gregg (1973, p. 16) and by Gregg and Zimmerman (1974, p. D17). The upper water-bearing zone includes the uppermost part of the Ocala and ranges in thickness from about 75 to 150 ft. It is a very fossiliferous, permeable limestone that contributes about 70 percent of the water to wells that tap both zones. The lower water-bearing zone includes the basal Ocala and the uppermost part of middle Eocene rocks, and ranges in thickness from about 15 to 110 ft. It is a recrystallized dolomitic limestone, less permeable than the upper water-bearing zone, and contributes about 30 percent of the water to wells that tap both zones. The two zones are treated as a single aquifer (Upper Floridan) in this study. Water-supply wells in the area of Brunswick generally do not tap water-bearing units beneath the Upper Floridan.

Although Miller (1985) included the Oligocene Suwannee Limestone, which overlies the Ocala, in the Upper Floridan in the area of Brunswick, the Suwannee is thin and yields insignificant quantities of water when compared with the upper and lower water-bearing zones.

In the area of Savannah, Ga., the Upper Floridan consists chiefly of two permeable zones—"zones 1 and 2" described by McCollum and Counts (1964, p. D9). These permeable zones were delineated on the basis of current-meter tests made in open holes in the Savannah area. Zone 1 is in the basal part of the Suwannee Limestone and the top part of the Ocala and is generally less than 50 ft thick. Zone 2 is near the middle of the Ocala and ranges from 25 to 75 ft in thickness. Zones 1 and 2 generally yield more than 70 percent of the water pumped from open holes tapping the entire aquifer system (McCollum and Counts, 1964). The two zones are treated together as the Upper Floridan aquifer in this study. Water-supply wells in the area of Savannah generally do not tap water-bearing zones beneath the Upper Floridan.

In the southern tip of South Carolina, the Upper Floridan is the "upper permeable zone" described by Hayes (1979) and Spigner and Ransom (1979). There, the Upper Floridan consists of the basal part (late Eocene age) of the Cooper Formation and the upper part of the Santee Limestone of middle Eocene age. The Upper Floridan is more than 200 ft thick in the extreme southern part of the area and thins toward the north until it pinches out near the Combahee River (pls. 1, 2, 5). The Upper Floridan is the primary source of ground water in most of the southern part of South Carolina.

In the northeast Florida area, the Upper Floridan consists of the Ocala Limestone (the "Ocala Group" of the Florida Geological Survey) (Leve, 1966, p. 11, 24). The Ocala is a sequence of permeable, hydraulically connected marine limestone that contains few low-permeability carbonate beds to restrict vertical movement of water (Leve, 1966, p. 24). The Upper Floridan contributes about one-half of the water pumped from wells tapping the entire Floridan aquifer system in the Jacksonville area. Head difference between the Upper Floridan and the underlying Lower Floridan is generally less than 2 ft in that area (Leve, 1966, p. 25). However, head differences between the Upper Floridan and the Lower Floridan may be as much as 20 ft in areas of large withdrawals from the Upper Floridan, such as that in the area of Fernandina Beach, Fla. (Fairchild and Bentley, 1977, p. 13).

In the western part of the study area, the Suwannee Limestone of Oligocene age forms the major part of the Upper Floridan aquifer. The Suwannee Limestone is similar in character to the Ocala but is more fossiliferous and somewhat sandy and phosphatic. The development of secondary permeability was similar to that in the

Ocala, making the Suwannee highly permeable. Secondary permeability is greatest at the erosional unconformity between the Ocala and the overlying Suwannee Limestone. The permeable zone at the Suwannee–Ocala unconformity is a major source of water in the Upper Floridan aquifer, especially in the area of Valdosta, Ga. (Krause, 1979, p. 10). An erosional unconformity containing highly developed secondary permeability is also present between the Suwannee and the overlying sandy limestones of early Miocene age in the Valdosta area. This zone is also a significant part of the Upper Floridan in that area (Krause, 1979, p. 10). In the Valdosta area, the Upper Floridan aquifer is the sole producing zone in the Floridan aquifer system. There, the Lower Floridan has low permeability and a sluggish, nearly static flow system that is isolated from the rest of the aquifer system, contains mineralized water, and herein is not considered part of the aquifer flow system.

In the extreme updip part of Georgia, the Upper Floridan aquifer consists chiefly of the Barnwell Formation of late Eocene age, which grades by facies change to the Ocala Limestone. The Upper Floridan extends updip to the late Eocene facies that consists of less than 50 percent carbonate (Miller, 1982d). The Oligocene Suwannee Limestone is a minor part of the Upper Floridan in all but the extreme updip area.

LOWER FLORIDAN AQUIFER AND MIDDLE SEMICONFINING UNIT

The Lower Floridan over most of the study area consists chiefly of middle to lower Eocene carbonate rocks, less fossiliferous and more dolomitic than the overlying Upper Floridan. Permeability is primarily secondary and is developed along bedding planes and other zones of weakness. The Lower Floridan is an insignificant contributor to wells tapping the entire Floridan aquifer system except in the area of Jacksonville, Fla., and east of the Combahee River in South Carolina. In extreme southeast Georgia and northeast Florida, the Lower Floridan includes a mappable water-bearing zone, formally designated the "Fernandina permeable zone." This zone, lying at the base of the Lower Floridan aquifer, is distinctive in its flow characteristics in this study area and is considered a separate water-bearing unit. Discussions of the Lower Floridan in this section exclude the Fernandina permeable zone, which is discussed in the following section.

In the updip part of the study area, the Lower Floridan as defined by Miller (1982b; 1985) does not exist. In parts of the updip area, Miller combined the Upper and Lower Floridan and termed them the "Upper Floridan." In other parts of the updip area, he excluded the Lower Floridan from the aquifer system because rocks that make up the water-bearing zone consist chiefly of clastic material. For this study, the Lower Floridan is considered a separate unit and, even where clastic, a part of the active flow system.

In the area of Jacksonville, Fla., the Lower Floridan (exclusive of the Fernandina permeable zone) consists chiefly of the middle Eocene Lake City Limestone of former usage (Leve, 1966, p. 29). The Lake City, as formerly used, was not differentiated stratigraphically from the overlying Avon Park Formation (also of middle Eocene age) in this report or in Miller (1985). However, Leve (1966, p. 14) made the distinction between the Lake City and the Avon Park on the basis of foraminifera. Miller (1985) abandoned the name Lake City Limestone and included the entire middle Eocene section in the Avon Park Formation—"formation" rather than "limestone" because the Avon Park contains significant amounts of dolomite. This report follows that usage. Lithologically, the entire middle Eocene section consists of alternating beds of limestone and dolomite, the lower part having well-developed secondary permeability.

The Lower Floridan is about 500 ft thick in the Jacksonville area, lying about 950 to 1,400 ft below land surface (Leve, 1966, p. 29). Within the Lower Floridan are zones of high and low permeability. Leve (1966, p. 29) reported that two permeable zones exist in this sequence—an upper zone between about 950 and 1,200 ft below land surface and a lower zone between about 1,250 and 1,400 ft. As described by Leve (1966), the two zones are separated by hard limestone and dolomite in the Lake City (of former usage) and have somewhat different head and yield characteristics.

The Lower Floridan is confined above by hard, low-permeability limestone and dolomite of the upper part of the middle Eocene Avon Park Formation (Miller, 1985) and the basal part of the upper Eocene Ocala Limestone (Leve, 1966). This hard, low-permeability limestone, called the middle semiconfining unit, is of sufficiently low permeability to cause some head difference between the Upper and Lower Floridan. (See discussion of Jacksonville area in earlier section on the "Upper Floridan Aquifer.") This semiconfining unit locally is breached by faults or fractures that facilitate leakage, generally from the Lower to the Upper Floridan, where the head difference is sufficient. (Leakage is discussed in a later section.) About one-half of the water pumped by large municipal and industrial wells in the Jacksonville area is withdrawn from the Lower Floridan.

The Lower Floridan in the area of Fernandina Beach, Fla., is similar to that in the Jacksonville area, except there is no confinement within the Lake City Limestone (of former usage; Leve, 1966, p. 30) and the Lower Floridan is more deeply buried. Almost no water is withdrawn from the Lower Floridan in the Fernandina

area; however, the zone leaks water to the Upper Floridan where the Upper Floridan is heavily pumped.

The Lower Floridan in the area of Brunswick, Ga., consists of interbedded limestone and dolomite of the lower two-thirds of the middle Eocene, and the upper part of the lower Eocene. The Lower Floridan in this area includes the "brackish-water zone" and the "deep freshwater" described by Gregg and Zimmerman (1974, pl. 1). Neither of these zones is tapped by supply wells in the Brunswick area, but water from the zones leaks upward through faults or fractures in the middle semiconfining unit into the Upper Floridan. The middle semiconfining unit consists of dense, low-permeability, recrystallized limestone and dolomite near the top of the middle Eocene section.

In the area of Savannah, Ga., and Hilton Head Island, S.C., the Lower Floridan consists of dolomitic limestone of middle Eocene age. In the Savannah area, the Lower Floridan represents permeable zones 3, 4, and 5 described by McCollum and Counts (1964, p. D9), as determined from current-meter tests made in wells. The Lower Floridan is not tapped for water supply in the Savannah area. However, it responds to pumping from the Upper Floridan, as indicated by the similarity of water levels observed in the Upper and Lower Floridan aquifers (fig. 9). This suggests that the Lower Floridan is hydraulically connected with the Upper Floridan.

In the area of Hilton Head Island, S.C., the Lower Floridan is similar to that at Savannah, but individual permeable zones have not been reported. The Lower Floridan in this area is the "lower permeable zone" described by Hayes (1979) and Spigner and Ransom (1979), which is the Santee Limestone of the basal middle Eocene. The lower permeable zone consists of a siliceous, glauconitic limestone having secondary permeability. It is less than 100 ft thick in this area. In the extreme northeastern part of the study area in South Carolina, the Upper Floridan is not present (pls. 1, 5) and the Lower Floridan is the primary source of ground water. The middle semiconfining unit there is a soft, siliceous, argillaceous, marly limestone of low permeability that ranges in thickness from about 200 to 900 ft.

Downdip from the Gulf Trough in middle Georgia, the Lower Floridan consists chiefly of siliceous, argillaceous limestone of middle Eocene age. The Lower Floridan, as a permeable carbonate facies within the entire Floridan aquifer system, extends only to about the Gulf Trough. Updip from the Gulf Trough, the character of rocks stratigraphically equivalent to the downdip carbonate facies changes considerably. In the updip area, the aquifer grades northward from a carbonate facies along the trough to clastic facies along the updip extent of the aquifer system.

Updip from the Gulf Trough, the Lower Floridan, according to Miller's (1985) framework of the aquifer system, does not exist. In that area, Miller limited the Floridan aquifer system to strata that are more than 50 percent carbonate. Although the units in this area are predominantly noncarbonate and are designated by different formation names, they are the clastic equivalents of Miller's Lower Floridan, differing only in lithology. The units are hydraulically part of the Lower Floridan flow system and therefore are treated as part of the Lower Floridan in this study. The clastic units consist of calcareous silt and sand, fossiliferous, glauconitic, sandy limestone, and clean quartz sand and gravel having high porosity and permeability. The units are chiefly part of the Huber Formation (Buie, 1978), the exact age of which is unknown, which occurs between two recognizable unconformities—one at the end of the Cretaceous and one at the end of the middle Eocene.

The middle semiconfining unit overlying the Lower Floridan is made up of low-permeability clay, siltstone, and argillaceous limestone of the basal part of upper Eocene strata. The unit grades into the adjacent Upper and Lower Floridan, and in places has moderate permeability and effective vertical hydraulic conductivity, in effect providing little separation between the aquifers.

Little is known of the extent, thickness, and character of similar facies of the Lower Floridan and the middle semiconfining unit in the inland part of the study area. Few data are available for the Lower Floridan and middle semiconfining unit, as only a few wells tap the Lower Floridan, especially in this inland area. Sufficient water supplies are generally obtained from the Upper Floridan, making drilling into the Lower Floridan unnecessary. Some oil-test wells have been drilled through the Lower Floridan; however, only geologic and geophysical data were obtained.

Fernandina Permeable Zone

The Fernandina permeable zone of the Lower Floridan aquifer was first tapped in 1945 by a 2,130-ft test well at Fernandina Beach, Fla., and that name is used herein. The zone consists of pelletal, recrystallized limestone and finely crystallized dolomite that has extremely high permeability and is locally cavernous. In the areas of Fernandina Beach and Jacksonville, the zone is in the basal lower Eocene and Paleocene—the Oldsmar and Cedar Keys Formations, respectively. In the area of Brunswick, Ga., the zone is lower stratigraphically and lies at a greater depth in rocks of Paleocene and latest Cretaceous age. Thickness of the zone ranges from about 100 ft in the Jacksonville area to more than 500 ft at Brunswick. The zone's approximate extent is shown on plate 3. The offshore extent

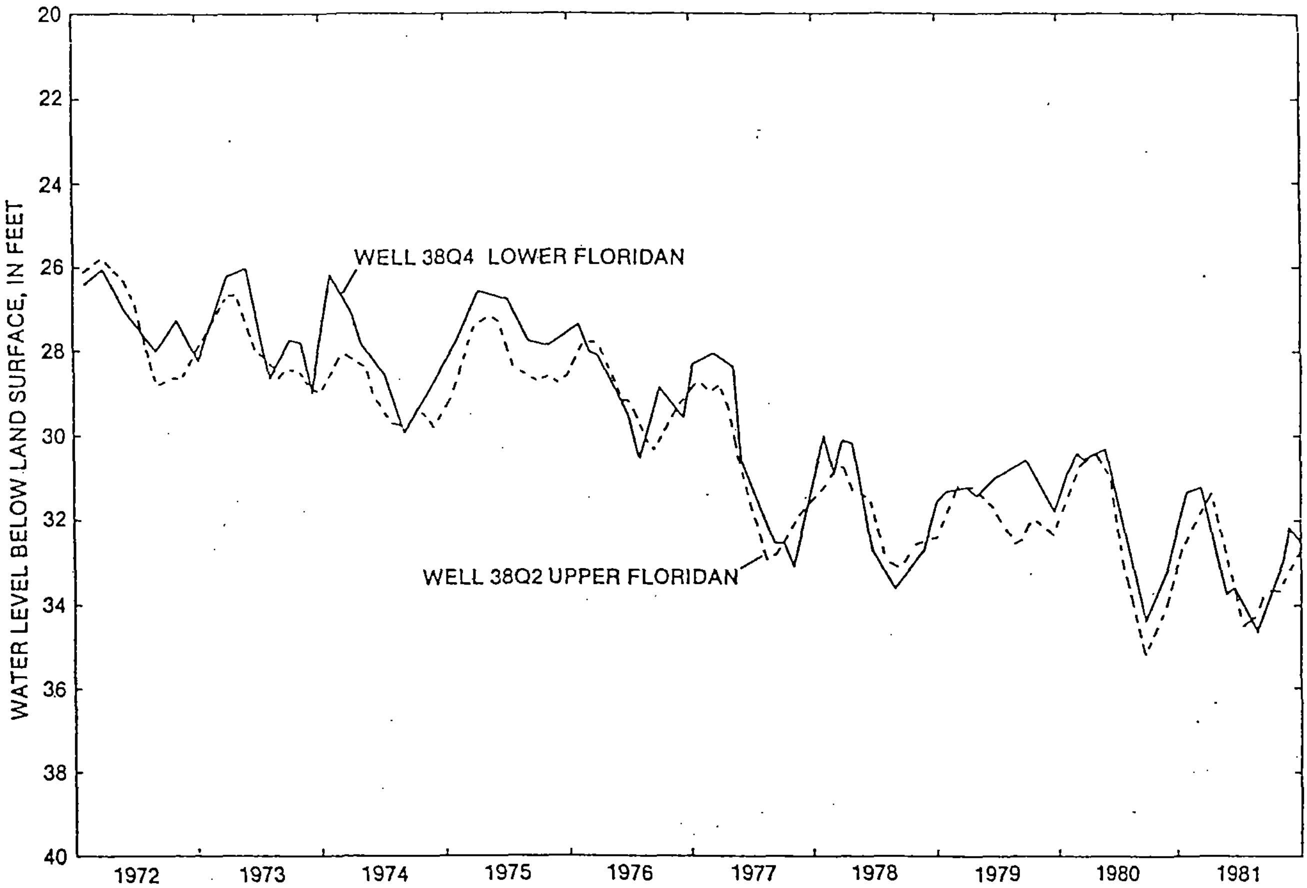


FIGURE 9.—Comparison of water levels in the Upper and Lower Floridan aquifers, Savannah, Ga.

of the zone is unknown, but it undoubtedly extends some distance offshore and may crop out on the ocean floor. Miller (1985) states that the semiconfining unit overlying the Fernandina permeable zone pinches out toward the south and southwest in Florida, and that the zone merges with the rest of the Lower Floridan aquifer.

Because few wells tap the Fernandina permeable zone, very little is known about its extent, thickness, and characteristics. Definition of the zone on the basis of geophysical logs is also made difficult because of the varying and largely unknown quality of its water and occurrence of cavernous zones.

The Fernandina permeable zone is confined above by low-permeability rocks of lower-middle to early Eocene age consisting chiefly of limestone and dolomite, nearly the same as the permeable zones adjacent to it. Vertical hydraulic conductivity of the lower semiconfining unit overlying the Fernandina permeable zone is low, except where it has been breached by faulting.

HYDRAULIC CHARACTERISTICS

Like the geologic data, the hydraulic characteristics of the Floridan aquifer system are primarily known for the Upper Floridan aquifer and the upper confining unit. Very few data are available for the middle and lower semiconfining units and the Lower Floridan aquifer. Almost all aquifer tests conducted in the Floridan in the study area have been of the Upper Floridan. Of these tests, most were made in wells penetrating the upper part of the Upper Floridan. No aquifer tests have been made exclusively in the Lower Floridan. Only one aquifer test, conducted near Waycross, Ga., as part of this study, has been made in wells that tap the entire thickness of the Floridan aquifer system.

Hydraulic characteristics of the Floridan aquifer system vary greatly within the study area, owing to the heterogeneity (and locally to the anisotropy) of the

aquifers and to the confinement (or lack of confinement) provided by the confining units.

AQUIFERS

Hydraulic conductivity and transmissivity of the Upper and Lower Floridan aquifers are generally lowest in the areas of outcrop, along the extent of the aquifers in South Carolina and probably offshore and along the Gulf Trough. Hydraulic conductivity and transmissivity generally increase downdip and downgradient from the Gulf Trough throughout Georgia, then decrease near the Florida–Georgia State line, and finally increase farther south in northeast Florida.

The heterogeneity of the aquifer system is chiefly related to the development of secondary porosity and permeability in the carbonate rocks. Secondary porosity and permeability are developed by circulating ground water as it flows through bedding-plane separations, faults, joints, fractures, and other zones of weakness in the carbonate and enlarges them by solution. Anisotropy of the aquifer is, in places, enhanced by the preferential orientation of structural features along which ground water flows. In the area of Valdosta, Ga., Krause (1979, p. 9) concluded that uplift during the Miocene produced northwest–southeast- and northeast–southwest-trending joints along which preferential ground-water flow developed. The directions of preferential flow are indicated by trends in surface drainages, alignments of karst physiographic features, and areal variations in water quality.

Cavities, cavernous zones, and solution channels tens of feet in vertical and horizontal dimensions have been tapped by wells throughout the downgradient part of the Floridan aquifer system in southeast Georgia and northeast Florida. These zones are chiefly in the Upper Floridan, but some of the largest are in the Lower Floridan and its Fernandina permeable zone in extreme southeast Georgia and northeast Florida. Most of the cavernous zones and solution channels are oriented in the horizontal plane, enhancing lateral permeabilities. However, some solution channels are oriented along nearly vertical planes and probably formed along zones of weakness caused by high-angle fractures and faults. These nearly vertical conduits locally connect permeable zones within the entire Floridan aquifer system along the coast in extreme southeast Georgia and in northeast Florida. Although faults are believed to be present along the southeast Georgia coast (D.C. Prowell and H.E. Gill, U.S. Geological Survey, written commun., 1983), they have not been mapped by Miller (1985) and are not shown on the structure maps in this report.

Conversely, structure in the form of nearly vertical faulting has locally decreased the lateral permeability of the aquifer system. The most pronounced effects of faulting and lateral permeability reduction in the aquifer system are in the area of the Gulf Trough. There, high-angle faults probably have juxtaposed permeable zones nearly opposite to zones of low permeability, markedly decreasing what probably had been continuous lateral permeability. Infilling of low-permeability clastic material in the grabens further decreased permeability. Even in the downgradient area along the southeast Georgia–northeast Florida coast, where only carbonate rocks of the aquifer system were faulted, some of the high-angle faulting has probably decreased lateral permeability.

Hydrogeologic differences within the Upper and Lower Floridan aquifers result in large variations in hydraulic properties within short distances. Estimated hydraulic conductivity increases from less than 5 ft/d in the western part of the Gulf Trough to greater than 500 ft/d less than 10 mi downdip from the trough (pl. 7). Hydraulic properties vary in even shorter distances because of the extreme areal variability of secondary porosity and permeability. The transmissivity values derived from some of the aquifer tests did not approximate the regional transmissivity values simulated during this study. Some values obtained from aquifer tests are considerably lower than those simulated. Probable causes of this discrepancy are that these aquifer tests were too short, or were conducted on wells that partially penetrated the aquifer or that tapped parts of the aquifer lacking fractures or solution conduits that control flow on the regional scale.

The transmissivities shown on plate 7 are from a variety of sources. In order of descending reliability, those sources are (1) multiwell aquifer tests using the Theis analysis, (2) single-well aquifer tests using the Cooper-Jacob approximation, and (3) estimation from specific-capacity data. Bush and Johnston (in press) used a statistical analysis of transmissivity values of the Floridan aquifer system and concluded that the relation between transmissivity values estimated from specific-capacity data and those obtained from simulation was minimal, and that the transmissivity estimated from specific capacity is almost always less than that from simulation. They also concluded that transmissivity values derived from aquifer tests were slightly less than those simulated, but that they were in better agreement with simulated values than were those estimated from specific-capacity data. Specific capacity is thus not a particularly good basis from which to estimate transmissivity in most parts of the Floridan aquifer system. Transmissivities obtained from multiwell aquifer tests (where pumping and observation wells are hundreds of

feet apart) more nearly equal the simulated transmissivity values, which represent the regional flow system.

Hydraulic conductivity of the Upper Floridan shown on plate 7 was estimated from aquifer tests and ranges from less than 5 ft/d to more than 1,000 ft/d. Transmissivity ranges from less than 1,000 ft^2/d to nearly 1,000,000 ft^2/d (pl. 7). Actual ranges of hydraulic conductivity and transmissivity, which control ground-water flow on a regional scale, are probably greater. Hydraulic conductivity and transmissivity approach zero at the outcrop limit of the aquifer, where thickness approaches zero, and become extremely large near springs and swallow holes, where water moves through solution channels as much as tens of feet in diameter.

Most of the data on plate 7 are from aquifer tests made along the heavily developed and intensively studied coast. Because of the paucity of data on hydraulic properties of the aquifer system in the inland area, an aquifer test was conducted during this investigation at an area of suspected high transmissivity near Waycross, Ga. The two wells constructed for the test penetrated the entire Floridan aquifer system. However, all of the flow was derived from the Upper Floridan aquifer. Matthews and Krause (1984) describe the test drilling and aquifer testing in detail. Only a brief summary of the aquifer test follows.

The aquifer test was conducted June 16–19, 1981, at a site about 9 mi southeast of Waycross, Ga. (pl. 7), where the Floridan aquifer system is moderately thick and the transmissivity was believed to be very large. The aquifer system is about 1,250 ft thick, extending from about 600 to 1,900 ft below land surface, which has an altitude of about 150 ft.

A nearly constant rate of 2,040 gal/min was maintained in the pumped well for 47 h. Water-level measurements were made in the observation well, 154 ft away, throughout the pumping and recovery periods. The orifice method was used to measure the pumping rate. Electric and wetted-tape methods and water-level recorders were used for water-level measurements.

Complicating factors during the test included (1) minimal water-level decline of less than 0.5 ft in the observation well, (2) cyclic fluctuations in the water level (probably the result of earth tides) nearly as great as the decline induced by pumping, and (3) a seasonal water-level decline that encompassed the test period. These factors precluded the determination of definitive values of the aquifer properties.

Figure 10 is a plot of the drawdown adjusted for the regional water-level decline versus time for the observation well. The cyclic water-level fluctuations were not the result of barometric fluctuations (Matthews and Krause, 1984, p. 13, fig. 3) but, as stated, were probably caused by earth tides. These fluctuations were ignored and the Theis-type curve was superposed through a graphic median of the data as shown in figure 10.

Using the match points for the Theis curve and associated parameters shown in figure 10, the transmissivity was calculated to be about 1,000,000 ft^2/d. A storage coefficient of 0.0001 was calculated, but its accuracy is questionable. It is, however, similar to values reported elsewhere in the thickly confined area. Although the aquifer test was conducted using wells that fully penetrated the Floridan aquifer system, a borehole-flowmeter survey taken when the pumping well discharged 1,900 gal/min indicated negligible (unmeasurable) flow from depth below about 1,100 ft. This indicates that the discharge is entirely from the Upper Floridan aquifer.

The transmissivity determined from this aquifer test is the largest ever derived from a pumping test for the freshwater interval of the Floridan aquifer system. Higher values have been determined by areal, flow-net methods in the area of springs in north-central Florida. Faulkner (1973, p. 93–96) determined transmissivity by flow-net analysis to be an average of more than 2,000,000 ft^2/d around Silver Springs. One segment of the flow net had an estimated transmissivity of more than 25,000,000 ft^2/d.

Although undetermined to date, higher transmissivity also probably exists along the coast in southeast Georgia. Highest hydraulic conductivities in the study area are recorded there (pl. 7) and the Floridan aquifer system, which includes rocks of Late Cretaceous age, is thickest there (pl. 1). Caliper and sonic televiewer logs and borehole television traverses made in a test well near Brunswick, Ga., showed extensive caverns throughout the Floridan aquifer system.

In contrast to these extremely large transmissivities, values of less than 1,000 ft^2/d in the area along the Gulf Trough have been determined by estimates from specific-capacity data. Low values are expected there because of faulting, juxtaposition of permeable and nonpermeable zones, and clastic infilling. Low transmissivity also occurs in the outcrop areas and at the physical limits of the aquifer due to thinning of the aquifer system. The areal distribution of transmissivity of the Upper Floridan aquifer as simulated by the flow model is shown on plate 8. The transmissivity distribution is in good agreement with those derived from field data (pl. 7).

Transmissivity data for the Lower Floridan aquifer are nearly nonexistent. Estimates of transmissivity were based primarily on thickness and qualitative estimates of permeability made from geophysical well logs. Transmissivity of the Lower Floridan aquifer probably ranges from about 2,000 ft^2/d to nearly 400,000 ft^2/d.

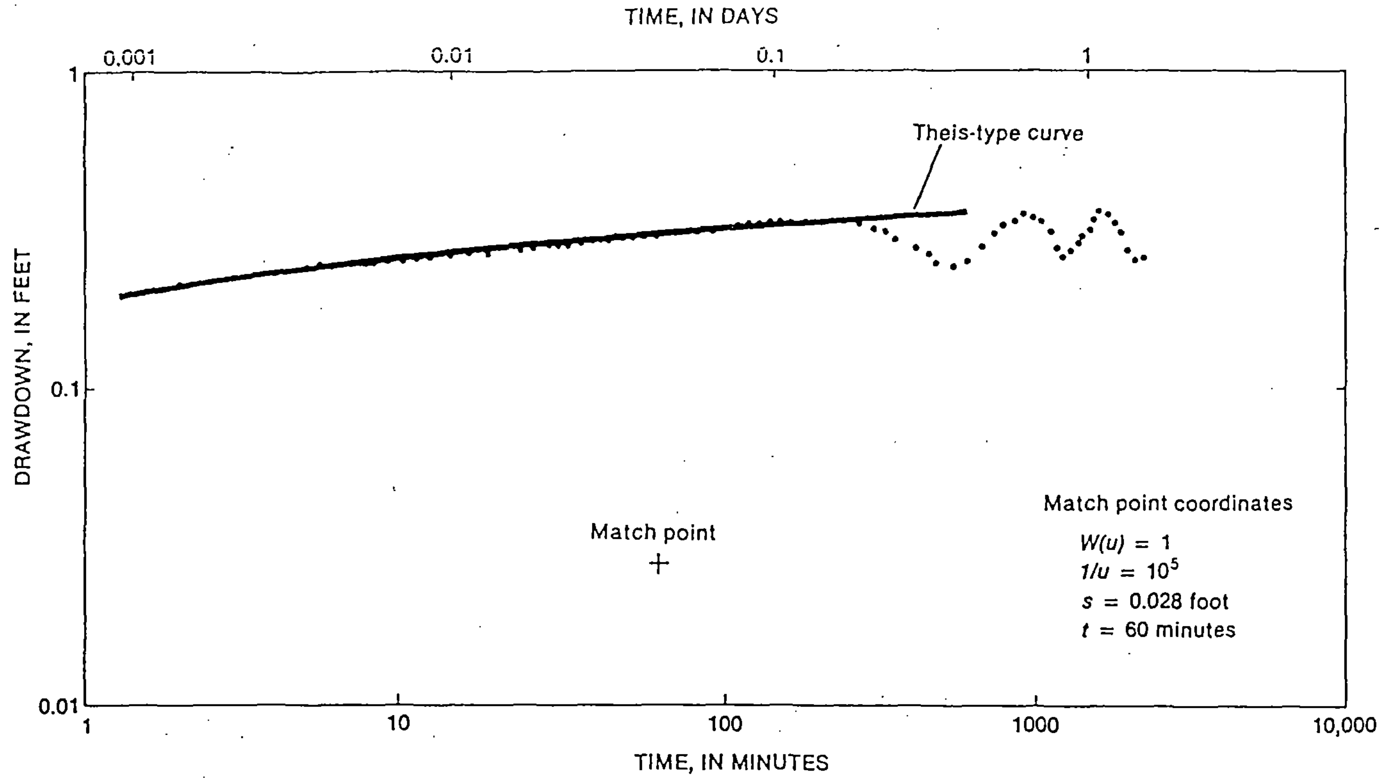


FIGURE 10.—Logarithmic plot of drawdown (*s*) in the observation well versus time (*t*) from the Waycross aquifer test, superposed on the Theis type curve (nonleaky, artesian). From Matthews and Krause (1984).

Transmissivity of the Lower Floridan generally decreases from south to north within the carbonate sequence downdip from the Gulf Trough. It is highest in northeast Florida, especially in the area of Jacksonville, where it is nearly 400,000 ft^2/d and the Lower Floridan yields about half the water withdrawn there from the Floridan aquifer system. The transmissivity of the Lower Floridan is probably less than 100,000 ft^2/d everywhere except in northeast Florida and extreme southeast Georgia. In the Savannah, Ga., area, the transmissivity of the Lower Floridan is probably less than 10,000 ft^2/d. Because the Lower Floridan includes thick sequences of permeable clastic material near the outcrop area of the aquifer system, transmissivity of the Lower Floridan is higher there than it is downdip in most of central Georgia. Transmissivity values there range from about 10,000 to 40,000 ft^2/d, based on simulation.

Transmissivity of the Fernandina permeable zone is less well known than that of the rest of the Lower Floridan. The hydrogeology of the Fernandina permeable zone based on borehole geophysical data gives some indication of the relative transmissivity of the zone. Borehole television and caliper logs of a test well 3 mi southwest of Brunswick, Glynn County, Ga., showed cavities, or conduits, in the Fernandina permeable zone that were tens of feet in height and of undetermined lateral extent. A similar cavernous zone in the Lower Floridan in South Florida has a transmissivity greater than 3,000,000 ft^2/d (Meyer, 1974). Borehole geophysical logs indicate that the Fernandina permeable zone is cavernous and has high permeability in northeast Florida, although somewhat less than at Brunswick. Transmissivity probably decreases markedly from those areas and approaches zero at the limit of the zone's extent. Also, if the zone extends toward the south and southwest in Florida and merges with the rest of the Lower Floridan aquifer (Miller, 1985), its transmissivity would not, of course, approach zero in that area.

CONFINING UNITS

Hydraulic data for the confining units are more sparse than those for the aquifers. Except for laboratory analyses of the vertical hydraulic conductivity of cores

from the middle semiconfining unit at Brunswick, Ga. (Wait and Gregg, 1973, p. 42), the only data available are for the upper confining unit.

In Brunswick, Ga., vertical hydraulic conductivity of the upper confining unit, as determined by laboratory analyses of cores, ranged from 5×10^{-5} ft/d (Wait, 1965, p. 48) to 1.1 ft/d (Wait and Gregg, 1973, table 9). Vertical hydraulic conductivity suggested by simulation is about 1×10^{-5} to 1×10^{-3} ft/d. A hydraulic conductivity of 1×10^{-4} ft/d for a 475-ft confining-unit thickness results in a leakance of 2.1×10^{-7} d^{-1}. A 25-ft head difference between the surficial and the Upper Floridan aquifers would effect leakage of about 0.02 in/yr through the upper confining unit.

An average vertical hydraulic conductivity of 1.3×10^{-3} ft/d was determined by laboratory analyses of 52 cores taken from the upper confining unit (Miocene Hawthorn Formation) at various locations in Chatham County, Ga. (Furlow, 1969, p. 23). The cores were taken from within a 40-ft sequence of a fuller's earth type of clay that probably represents the least permeable part of the upper confining unit. The average hydraulic conductivity of the entire upper confining unit is undoubtedly greater than the laboratory-determined values because of the presence of more permeable strata in the unit. Leakance of the 40-ft sequence having a vertical hydraulic conductivity of 1.3×10^{-3} ft/d would be 3.2×10^{-5} d^{-1}. Leakage through the sequence under the prevailing vertical head difference of 15 ft would be 2.1 in/yr.

In the area of Baker and Columbia Counties, Fla., just southwest of the study area, vertical hydraulic conductivity of the upper confining unit (Hawthorn Formation) was determined by laboratory analyses of cores to range from 1.5×10^{-2} to 7.8×10^{-7} ft/d, and by extensometer analysis to be about 2×10^{-4} ft/d (Miller and others, 1978, table 17).

An estimated conductivity of 1×10^{-4} ft/d for the 10-ft "D member" of the Hawthorn Formation (Miller and others, 1978) results in a leakance of 1×10^{-5} d^{-1}. Leakage through that unit would be 0.04 in/yr under the prevailing vertical head difference of 1 ft. The hydraulic conductivity of 2×10^{-4} ft/d from the extensometer analysis, for the 14-ft "Lower B member" of the Hawthorn results in a leakance of 1.4×10^{-5} d^{-1} (Miller and others, 1978). Leakage through that unit would be about 0.06 in/yr under the 1-ft head difference.

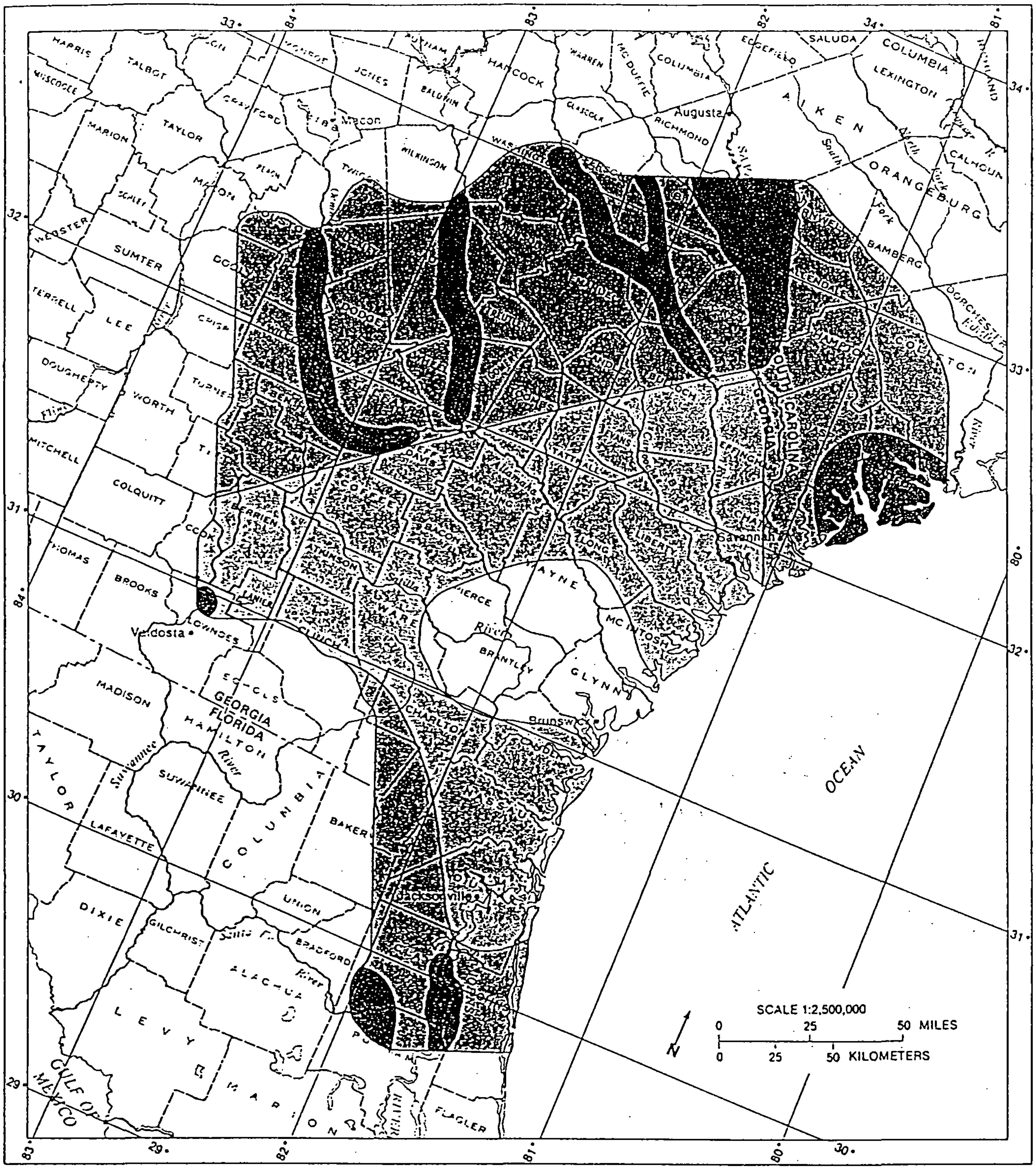
In the southern part of St. Johns County, Fla., just south of the study area, a vertical hydraulic conductivity of the upper confining unit of 1.1×10^{-2} ft/d and a leakance of 3.8×10^{-4} d^{-1} were determined by using a geometric analysis of the potentiometric surface (Bermes and others, 1963, fig. 26). For the analysis, the assumption was made that flow conditions were at steady state; transmissivity was known from aquifer-test analyses, and the water-table altitude was known. Leakage through the unit under the prevailing vertical head difference of 2.5 ft would be 4.2 in/yr.

The materials that make up the upper confining unit vary greatly in lithology and permeability and are complexly interlayered throughout a vertical section. Although values of the vertical hydraulic conductivity of the upper confining unit vary by orders of magnitude within a vertical section, a composite or average value for the full section probably does not vary much areally. Thus, the leakance of the upper confining unit would vary inversely with its thickness (pl. 4).

Under these conditions, leakances would be lowest in the Southeast Georgia embayment where the upper confining unit is thickest, and highest where the unit is thinner, as in the area updip from the Gulf Trough. Leakance is greatest in areas where the upper confining unit is largely absent, as along the major rivers updip from the Gulf Trough, and in the areas of Valdosta, Ga., Keystone Heights and Green Cove Springs, Fla., and Beaufort County, S.C. (fig. 11). Leakance of the upper confining unit shown in figure 11 is based on the thickness of the unit and the results from the simulation of the flow system (discussed in Supplement I).

The vertical hydraulic conductivity of the middle semiconfining unit is known only from laboratory analysis of five cores of two wells in Brunswick, Ga. The vertical hydraulic conductivity of the dolomitic limestone making up the middle semiconfining unit ranged from 4.0×10^{-6} to 5.4×10^{-5} ft/d. Leakance of the unit, which is about 100 ft thick and has an estimated vertical hydraulic conductivity of 1×10^{-5} ft/d, would be extremely low—about 1×10^{-7} d^{-1}. Leakage through that unit under a 7-ft head difference would be only 0.003 in/yr. The low vertical hydraulic conductivity and leakance is understandable for the dense dolomitic 100-ft-thick limestone. However, fractures and faults are known to be present in the Jacksonville, Fla., and Brunswick, Ga., areas and probably along the entire coast, and such fractures and faults would markedly increase the vertical hydraulic conductivity and leakance of this unit.

Field data for the lower semiconfining unit are unavailable. The hydraulic properties of the unit are known only from simulation.



Base from U.S. National Atlas, 1970

EXPLANATION

Leakance, in feet per day per foot

Less than 10^{-6}

10^{-6} to 10^{-5}

10^{-5} to 10^{-4}

More than 10^{-4}

FIGURE 11.—Estimated leakance distribution of the upper confining unit of the Floridan aquifer system.

PREDEVELOPMENT GROUND-WATER-FLOW SYSTEM

Ground-water flow in the Floridan aquifer system is controlled chiefly by rates and distribution of recharge to and discharge from the system, the extent and effects of confinement, and the ability of the aquifers to transmit and store water. Prior to development, the flow system is considered to have been at dynamic equilibrium and the potentiometric surfaces nearly unchanged from year to year. Recharge to the aquifers was balanced by natural discharge, resulting in no change in storage in the aquifer system on a long-term-average basis. Only seasonal and short-term climatic fluctuations affected the altitude of the potentiometric surface.

Dynamic changes to the flow system resulting from post-Pleistocene sea-level changes probably occurred prior to development. These changes would have altered all components of the predevelopment flow system—recharge and discharge, heads, flows, and the location of the freshwater-saltwater interfaces. However, sufficient time probably has elapsed for the flow system to reach equilibrium, and, therefore, steady-state conditions were assumed for this study.

POTENTIOMETRIC SURFACE

The estimated predevelopment potentiometric surface of the Upper Floridan aquifer in the study area is shown on plate 9 and is based on those by Johnston and others (1980) and by Krause (1982, pl. 2). Data used to construct these maps were (1) historic data gathered prior to development in areas that later had significant ground-water development, and (2) recent data from areas where development has had an insignificant effect on the potentiometric surface. Although the predevelopment potentiometric surface shown on plate 9 is that of the Upper Floridan aquifer, some data used in its construction were from wells that probably tap water-bearing zones in the lower part of the overlying Hawthorn Formation that are not considered part of the Upper Floridan aquifer. The water level in these wells would be slightly higher or lower than that in the Upper Floridan, depending on the vertical head gradient. Therefore, plate 9 shows the general configuration of the predevelopment potentiometric surface of the Upper Floridan aquifer in the study area and is not an accurate representation of site-specific water levels.

In the upgradient areas along the major rivers, especially the Savannah River, contours of the potentiometric surface on plate 9 differ slightly from those of Johnston and others (1980) and Krause (1982, pl. 2) because of the inclusion of more recent data. A recent investigation by Faye and Prowell (1982, fig. 8) indicates that a greater relation exists between the aquifer and the Savannah River than previously thought. The head in the aquifer is significantly lower near the river than away from the river, indicating that the aquifer discharges into the river. For that reason, the potentiometric contours in the vicinity of the river are markedly bent upgradient.

Although the relation between the aquifer and the other major upgradient rivers has not been documented, a similar steep gradient and discharge relation undoubtedly exists. These rivers exert more influence on the aquifer, as manifested in the potentiometric contours, than is shown on plate 9. The amount of influence would be related to the degree of river entrenchment, the thickness and leakance of material separating the aquifer and the riverbed, and the resistance to downgradient ground-water flow caused by the Gulf Trough, as well as to the head in the aquifer and the stage in the river.

COMPONENTS OF THE PREDEVELOPMENT GROUND-WATER-FLOW SYSTEM

Under predevelopment, steady-state conditions, recharge was equal to discharge and no change in aquifer storage took place. Recharge generally occurred in upgradient areas, producing high head. Water then flowed downgradient toward the coast and discharged in areas of lower head (pl. 9). The simulation indicates that total flow through the Floridan aquifer system in the study area prior to development was about 1,400 ft^3/s. Table 4 shows the simulated components and distribution of flow through the aquifer system prior to development.

The simulated distribution of vertical flow, or leakage, under predevelopment, steady-state conditions through the upper confining unit is shown on plate 10. The leakage is expressed in inches per year.

The area of highest recharge to the aquifer system prior to development was chiefly updip and upgradient from the Gulf Trough, where the aquifer system is exposed or thinly covered and least confined. In this area, recharge occurred in the topographically high areas, either directly into the exposed or thinly covered Upper Floridan or through the upper confining unit where the head in the surficial aquifer was higher than the head in the Upper Floridan. Flow through the Upper Floridan aquifer in this updip area was chiefly toward the major rivers, where the water was discharged. The components and areal distribution of simulated flow through the aquifer system prior to development are shown in figure 12.

In the area updip from the Gulf Trough, about 750 ft^3/s was recharged to the Upper Floridan from the surficial

TABLE 4.—*Simulated water budget for predevelopment (1880) and present-day (1980) flow systems*

[Negative number denotes opposite flow direction; values are rounded off only enough to maintain the numerical balance of the water budget; implication of accuracy to the degree shown is not intended]

	Simulated flow, in cubic feet per second													Pumpage, in cubic feet per second	
	Total flow		Net vertical leakage			Lateral boundary flow									
						Lower Floridan					Upper Floridan				
	In	Out	Surficial aquifer to Upper Floridan	Lower Floridan to Upper Floridan	Fernandina permeable zone to Lower Floridan	Northern inflow	Southern outflow	Eastern outflow	North-western inflow	South-western inflow	Southern outflow	Eastern outflow	South-western inflow	Upper Floridan	Lower Floridan
Predevelop-ment	1,400	1,400	-329	383	40	338	47	2	60	0	51	2	0	0	0
Present-day	2,100	2,100	92	612	282	338	47	-2	60	70	34	-6	201	878	93

aquifer and 990 ft³/s was discharged from the Upper Floridan, primarily to the major rivers. About 90 ft³/s infiltrated to the Lower Floridan, 456 ft³/s migrated from the Lower Floridan to the Upper Floridan, and 126 ft³/s migrated downgradient in the Upper Floridan through the Gulf Trough.

Circulation within the Lower Floridan in the area upgradient from the Gulf Trough was similar to that in the Upper Floridan, but of a smaller magnitude. In addition, because the Lower Floridan here is composed chiefly of clastic material, most of the flow occurred within these clastics, which are not a part of the (predominantly carbonate) Floridan aquifer system as defined by Miller (1985). The Lower Floridan was recharged with about 90 ft³/s from the Upper Floridan through the middle semiconfining unit. Because the clastic facies of the Lower Floridan aquifer extend farther updip and upgradient than shown and simulated herein, flow occurred from the clastics across the upgradient boundary of the model. This boundary flow was simulated to be about 338 ft³/s from the north and about 60 ft³/s from the northwest (fig. 12). The Lower Floridan discharged about 456 ft³/s through the middle semiconfining unit into the Upper Floridan. About 32 ft³/s remained in the Lower Floridan as downgradient flow through the Gulf Trough (fig. 12).

The small quantity of flow passing downgradient through the Upper and Lower Floridan aquifers across the Gulf Trough, compared with the total flow in the area upgradient from the trough, further supports the existence of an active but nearly isolated flow system in the Floridan upgradient from the Gulf Trough.

Ground-water contribution from the Floridan aquifer system to the major rivers and their tributaries in the area upgradient from the Gulf Trough was estimated from field data and subsequently simulated by the model. The estimates of the ground-water contribution were based largely on streamflow records from 13 gaging stations on the four major rivers: Ocmulgee, Oconee, Ogeechee, and Savannah. Summaries of 1-day, 7-day, and monthly minimum average flows made during the 1954 drought (Thomson and Carter, 1955, 1963) and annual low-flow data for periods of record were used. In addition, total discharge determined from instantaneous low-flow measurements made in tributaries to the major rivers was considered to be ground-water contribution to the streamflow.

The ground-water contribution of the Floridan aquifer system to the major rivers and their tributaries in the area upgradient from the Gulf Trough is considerably less than the observed base flow. A large part of the base flow is contributed by sources other than the Floridan aquifer system (most of which was not simulated by the model). These sources are the surficial aquifer and the updip clastic equivalents of the Floridan aquifer system. Stricker (1983) calculated the base flow to unregulated streams in selected basins in the Cretaceous-Tertiary outcrop area, which included part of this study area. Stricker used the method of hydrograph separation and concluded that discharges at the 65-percent duration point of flow-duration curves were good estimates of mean annual base flow. Using this criterion, an estimate of the base flow in most of the area upgradient from the Gulf Trough could be about 8 in/yr (Bush and Johnston, 1986). In this area, the local flow system (surficial aquifer) contributes most of the water to the base flow. Water in this local flow system either does not reach the Upper Floridan or, where it does and the Upper Floridan is the surficial aquifer, circulates on a scale that is smaller than that herein considered and simulated as part of the Floridan aquifer system. The Floridan aquifer system in this area probably contributes only about 1,000 ft³/s, or about 2 in/yr, to the base flow of the major rivers and their tributaries.

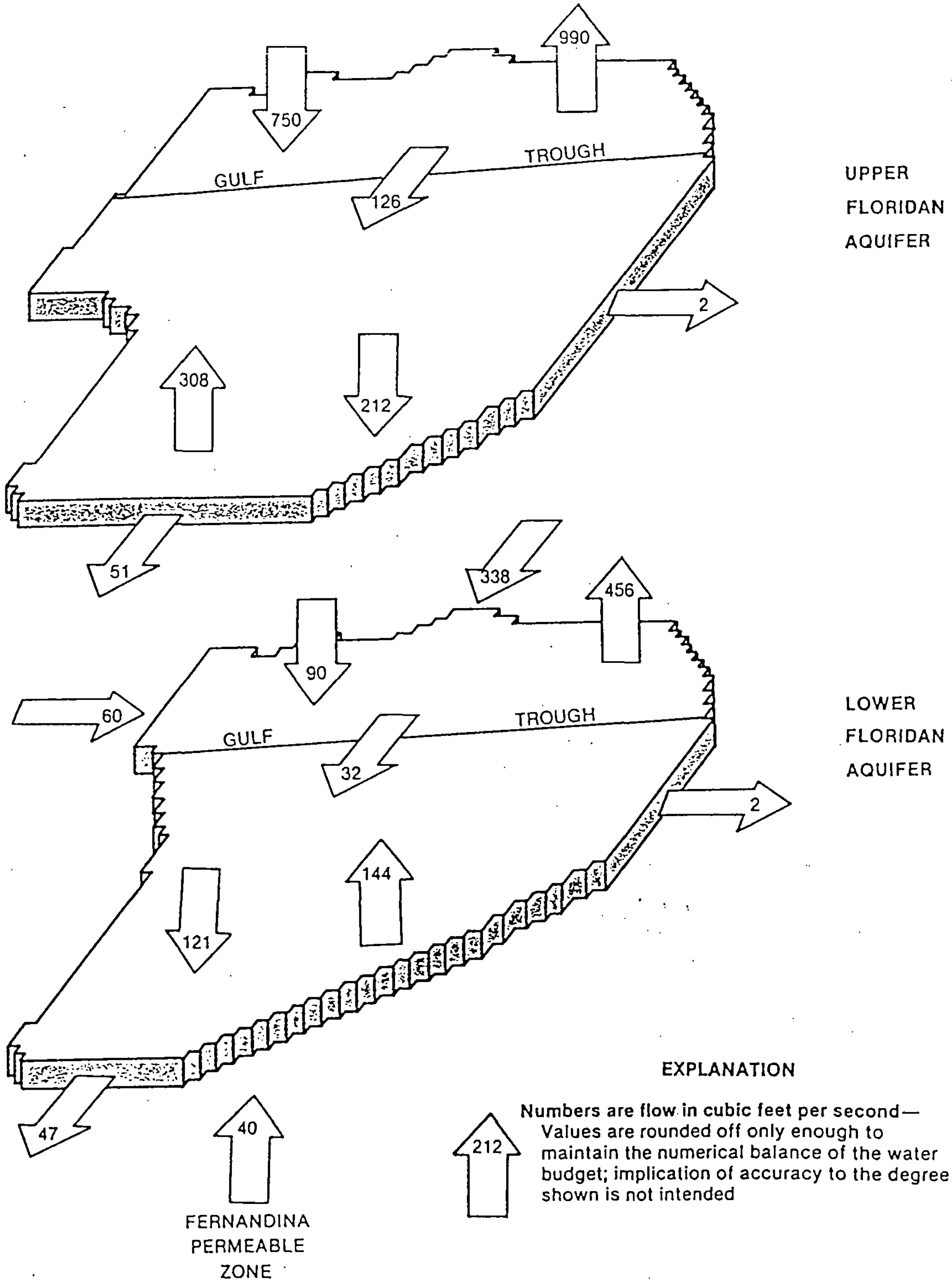


FIGURE 12.—Simulated components and areal distribution of flow through the Floridan aquifer system prior to development.

Total ground-water contribution to the major rivers was apportioned among the three aquifers: surficial (where different from the Upper Floridan aquifer), Upper Floridan, and Lower Floridan (which, in this area, is composed predominantly of clastic beds) on the basis of hydrogeologic framework and hydraulic characteristics of the aquifers. Estimated and simulated values are listed below.

Aquifer		Ground-water contribution to streamflow, in ft³/s			
		River			
		Ocmulgee	Oconee	Ogeechee	Savannah
Surficial[1]	Estimated	50	25	25	50
Upper Floridan	Estimated	220	80	70	190
	Simulated	247	83	65	200
Lower Floridan	Estimated	120	30	10	240
	Simulated	99	34	14	260
Total Floridan aquifer system	Estimated	340	110	80	430
	Simulated	346	117	82	460
Total	Estimated	390	135	105	480

[1]Surficial aquifer was not simulated.

Downgradient from the Gulf Trough, the flow system was more sluggish, characterized by flat gradients, high aquifer transmissivities, low velocities, and, with some exceptions, low recharge and discharge rates. Recharge and discharge over most of the downgradient area were chiefly low rates of diffuse infiltration or leakage. It is doubtful that the highly transmissive, cavernous nature of the aquifer system was developed under these conditions; it probably developed in the geologic past, as a result of either Pleistocene sea-level fluctuations, or, more likely, karstification during exposure of the Floridan carbonates shortly after deposition during Tertiary time. (See Miller, 1985, chapter B of this Professional Paper series, for a complete discussion of cavernous permeability development.)

The Upper Floridan aquifer in the area downgradient from the Gulf Trough received about 126 ft³/s as lateral downgradient flow through the trough (fig. 12). Recharge from the surficial aquifer to the Upper Floridan aquifer was about 212 ft³/s, and discharge from the Upper Floridan to the surficial aquifer was about 308 ft³/s, resulting in a net discharge of 96 ft³/s. Most of the recharge from the surficial aquifer to the Upper Floridan occurred as diffuse infiltration where the hydraulic gradient was downward in the large inland area away from the coast. Most of the discharge from the Upper Floridan to the surficial aquifer was diffuse upward leakage where the hydraulic gradient was upward, primarily in the coastal area. Discharge was concentrated in the Savannah, Ga., area, and along the St. Johns River, including Green Cove Springs, in Florida, where the upper confining unit is thin and locally absent.

Northeast Florida had the most active part of the predevelopment flow system downgradient from the Gulf Trough. There, the Upper Floridan aquifer is near land surface, and in places the upper confining unit is breached. Sinkholes, sinkhole lakes, sinking streams, and springs make this area typically karst. Recharge to the Upper Floridan, based on simulation, was about 60 ft³/s in the area near Keystone Heights in western Clay County, Fla. (pl. 10). Much of the water that recharged the aquifer near Keystone Heights was discharged in springs such as Green Cove Springs near the St. Johns River and unnamed springs along that river. Discharge also occurred as diffuse upward leakage from the Upper Floridan where leakance and head differences were favorable along the St. Johns River, totaling about 50 ft³/s.

Significant recharge to the Upper Floridan also occurred near Valdosta, Ga., where about 100 ft³/s enters the aquifer (Krause, 1979, p. 26), about 17 ft³/s of which enters the study area from the southwest. North of Valdosta, part and sometimes all of the Withlacoochee River flows into swallow holes that are interconnected with the aquifer (Krause, 1979, p. 11).

Recharge to the Upper Floridan aquifer of about 8 ft³/s occurred near Beaufort, S.C., where the aquifer is thinly covered. Discharge occurred nearby in deeply scoured reaches of creeks and estuaries near Hilton Head Island, S.C. (pl. 10).

In the area downgradient from the Gulf Trough, the Upper Floridan discharged about 51 ft³/s across the southern boundary into Florida and offshore and about 2 ft³/s into South Carolina and offshore across the eastern boundary. The Lower Floridan discharged about 144 ft³/s to the Upper Floridan aquifer, largely as diffuse upward leakage in the downgradient area along the coast where the vertical hydraulic gradient was upward. The Upper Floridan recharged the Lower Floridan at a rate of about 121 ft³/s, chiefly in the upgradient area near the Gulf Trough where the hydraulic gradient was downward (fig. 12).

The Lower Floridan aquifer in the area downgradient from the Gulf Trough received about 32 ft³/s as downgradient flow through the trough and discharged about 47 ft³/s and 2 ft³/s across the southern and eastern boundaries, respectively. The Lower Floridan had a net discharge of about 23 ft³/s to the Upper Floridan and received about 40 ft³/s from the Fernandina permeable zone (fig. 12). Because the hydraulic characteristics of the Fernandina permeable zone are poorly known and only roughly estimated, the simulated flux of 40 ft³/s may be in significant error.

The Fernandina permeable zone was fairly inactive prior to development. The approximately 40 ft³/s that discharged from the zone into the rest of the Lower Floridan aquifer occurred chiefly along the northeast Florida–southeast Georgia coast where the lower semiconfining unit is breached by faults (Leve, 1966; Gregg and Zimmerman, 1974). It is thought that water in the Fernandina permeable zone is, in part, relict or partially flushed connate water, probably having a nearly horizontal freshwater–saltwater interface. If the small quantity of water that leaked from the Fernandina permeable zone along the coast is approximately the same as the simulated quantity, that leakage probably did not significantly move the freshwater–saltwater interface within the zone. Although not known, the source of water that replaced the water lost by the zone may have been the Lower Floridan aquifer in central Florida, where the Fernandina permeable zone may merge with the rest of the Lower Floridan aquifer, or it may be modern seawater from the offshore area, or a combination of the two.

Downgradient from the Gulf Trough, for example in Jeff Davis County, Ga., where the head in the surficial aquifer was higher than the head in the Upper Floridan, circulation included diffuse recharge and downgradient flow (pls. 9, 10; fig. 13). Figure 13 is a schematic showing the predevelopment flow system in the Floridan aquifer system in the study area along a hypothetical flow line. Farther downgradient toward the southeast, the gradient between the surficial and Upper Floridan aquifers changed direction and discharge occurred. Still farther downgradient, near the coast, the head in the Upper Floridan exceeded land surface altitude and flowing wells were obtainable; diffuse upward discharge and downgradient flow still occurred (pls. 9, 10; fig. 13). Similar flow circulation of lesser quantities existed in the Lower Floridan aquifer.

The downgradient limit to the predevelopment freshwater flow system in the Upper Floridan was estimated to be near and approximately parallel to the Florida-Hatteras Slope (pl. 9). This limit for the aquifer flow system corresponds to the freshwater–saltwater interfaces within the aquifers (fig. 13).

The position of the freshwater-saltwater interface was estimated on the basis of an equation described by Hubbert (1940, p. 872). The assumption of the equation is that at the interface, pressure created by the freshwater head is balanced by pressure created by the saltwater head. The interface equation assuming flowing freshwater, static saltwater, and a sea-level datum is

$$Z=\left[\frac{p_f}{p_s-p_f}\right]\cdot h_f,$$

where

Z = altitude of the interface above a datum,
p_f = density of freshwater,
p_s = density of saltwater, and
h_f = freshwater head at the interface.

If p_f is assumed to be 1.000 g/cm³ for freshwater and p_s to be 1.025 g/cm³ for seawater, then

$$Z=40h_f.$$

This relation indicates that the depth below sea level to the base of freshwater is 40 times the altitude of the freshwater head at the interface. To estimate the interface position, it was assumed that the head at the interface was equal to the head of the potentiometric surface of the Upper Floridan as measured or estimated vertically above the interface. This condition is not precisely met because freshwater flow above the interface necessitates lines of equal head that are curved, not vertical. However, Johnston and others (1982, fig. 7) have shown that the interface offshore of southeast Georgia, which constitutes the limiting flow line of the freshwater flow system, has a very low slope. Therefore, freshwater flow lines near the interface must be nearly horizontal. This in turn suggests that the lines of equal head near the interface are nearly vertical. Thus, an estimate of the interface position based on heads higher in the section is probably acceptable.

PRESENT-DAY GROUND-WATER-FLOW SYSTEM

The present-day (1980) flow system reflects the changes that have occurred as a result of ground-water development. The flow system has undergone changes that involve water levels, rates and distribution of recharge and discharge, ground-water flow, and the quality of the water. Ground-water withdrawals primarily have lowered water levels, induced additional recharge and reduced natural discharge, and increased total flow through the system, and, to a lesser extent, have reduced aquifer storage, caused land subsidence (at Savannah), and degraded the quality of the water in places on the coast.

GROUND-WATER WITHDRAWAL

The first well drilled into the Floridan aquifer system in the study area was in Savannah, Ga., in 1885 (McCallie, 1898, p. 64). The city of Savannah began using ground water from the Upper Floridan in 1886, and by 1900 more than 10 Mgal/d (15 ft³/s) was withdrawn for municipal supply. Since then, development of ground water has spread throughout the area, chiefly along the coast, where flowing wells supplied suf-

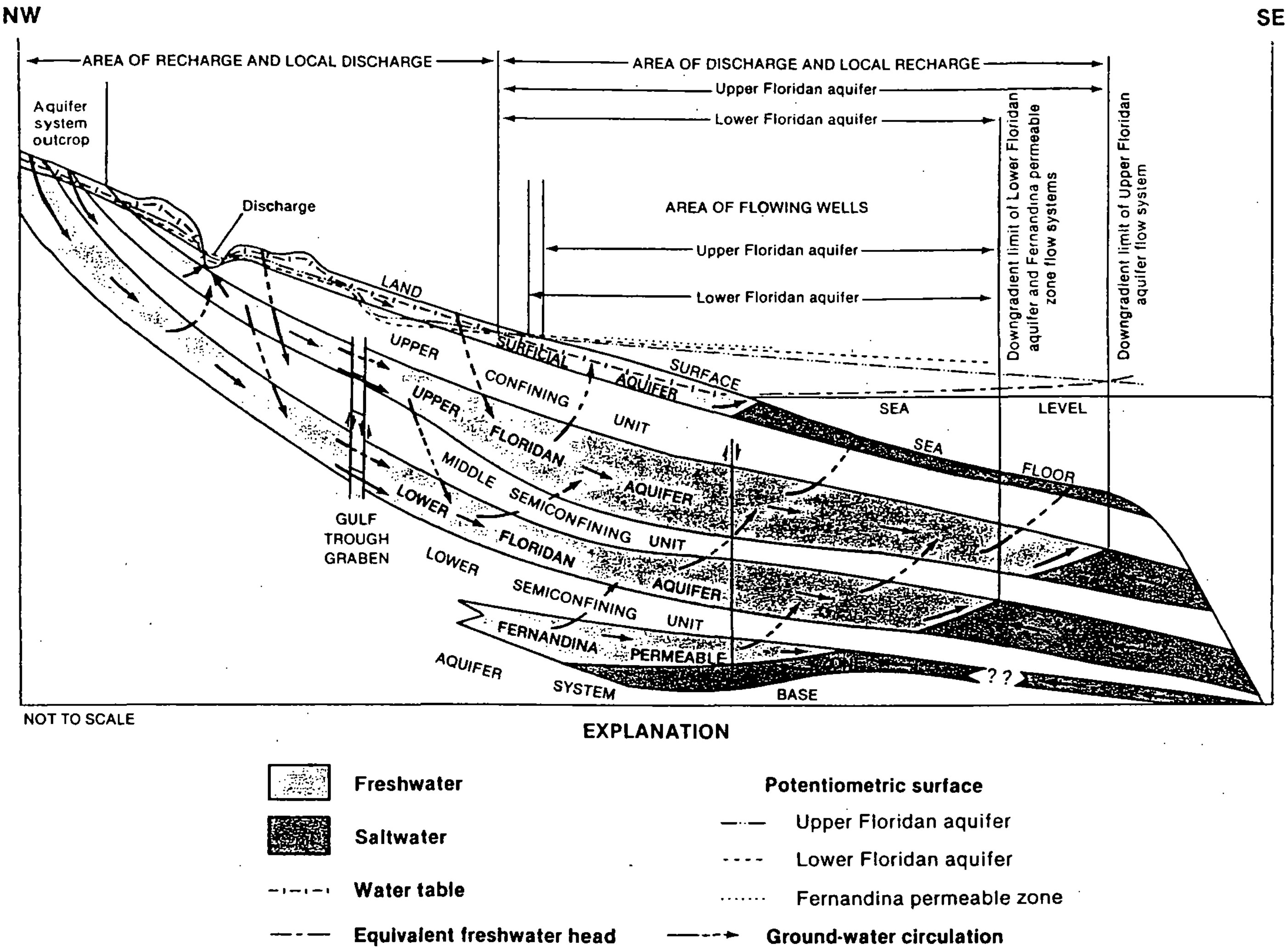


FIGURE 13.—Conceptual model of the predevelopment flow system for the Floridan aquifer system from the outcrop area in the northwest to the offshore area in the southeast.

ficient water to most users. Development continued to increase gradually, initially for municipal, domestic, and small commercial supplies. Large industries, chiefly paper manufacturers, located plants in the area and began to withdraw increasingly large quantities of water from the Upper Floridan, primarily along the coast. With the exception of the city of Jacksonville, Fla., the largest users of ground water are industries, and the major pumping centers are those that include ground water withdrawn by the pulp and paper industry.

In 1980, the total estimated ground-water withdrawal from the Floridan aquifer system in the study area was approximately 625 Mgal/d (970 ft^3/s). The distribution of pumpage for the study area by aquifer is shown on plate 11. The pumpage data were largely derived from Pierce and others (1982) for Georgia, Hayes (1979, p. 51, fig. 20) for South Carolina, and unpublished records (E.C. Hayes, U.S. Geological Survey, written commun., May 1981) for Florida. About 90 percent of the withdrawal was from the Upper Floridan. The 10 percent withdrawn from the Lower Floridan (about 93 ft^3/s) was chiefly in the Jacksonville area, where deep municipal and industrial wells tap both aquifers. A small quantity was withdrawn from the Lower Floridan in the outcrop area in Georgia, where neither aquifer is very productive, and in the area of South Carolina, where the Upper Floridan yields little water (pl. 11; table 4).

POTENTIOMETRIC SURFACE AND WATER-LEVEL DECLINE

The most obvious impact of ground-water withdrawal on the flow system has been the lowering of water levels. Large withdrawal of ground water along the coast has produced large cones of depression, which in places have overlapped, and generally has lowered potentiometric surfaces as far upgradient as the Gulf Trough (pl. 12). The potentiometric surface for May 1980 shown on plate 12 is that of the Upper Floridan aquifer in the study area, and is based on a similar map covering the entire Floridan aquifer system described by Johnston and others (1981). Although the potentiometric surface in the area upgradient from the Gulf Trough is believed to have been unaffected by ground-water development, the potentiometric surfaces for predevelopment (pl. 9) and present-day conditions (pl. 12), differ in that area. The present-day (1980) potentiometric surface is based on nearly synchronous measurements made during May 1980, whereas the predevelopment potentiometric surface is a general configuration, as previously discussed.

The potentiometric surface of the Lower Floridan is about the same as that of the Upper Floridan shown on plate 12. Sufficient data are not available to construct a 1980 potentiometric surface for the Lower Floridan. However, downgradient from the Gulf Trough, limited head data from both aquifers indicate that the head in the Lower Floridan is only slightly higher than that in the Upper Floridan. Maximum differences in heads between the Upper and Lower Floridan probably occur in the area of the deeper cones of depression and in areas where confinement is greatest and hence leakage is least. Fairchild and Bentley (1977, p. 13) indicated that at Fernandina Beach, Fla., the head in the Lower Floridan is as much as 20 ft higher than that in the Upper Floridan. This head difference probably represents a maximum; generally, head differences are less than 5 ft (fig. 9). However, locally in recharge areas upgradient from the Gulf Trough, where little withdrawal from the Upper Floridan has occurred since predevelopment, the head probably remains lower in the Lower Floridan. Similarly, head in the Lower Floridan is lower than in the Upper Floridan in the recharge areas near Keystone Heights, Fla., and Beaufort, S.C.

The deeper cones of depression of the potentiometric surfaces are in the areas of larger, concentrated ground-water withdrawal, such as Savannah, Ga., and Fernandina Beach, Fla. However, available water, supplied by lateral or vertical flow, plays a large part in the magnitude of head decline. In Georgia, pumpage at Brunswick is about 30 percent greater than that at Savannah, but higher transmissivity and leakance make more water available at Brunswick, thus producing a much shallower cone of depression. Pumpage of nearly 130 Mgal/d (200 ft^3/s) at Jacksonville, Fla., has produced an almost imperceptible cone for the same reasons, chiefly high leakage rates (pl. 12). Lowering of the potentiometric surface along the coast, especially near Savannah, has decreased the area where wells tapping the Floridan aquifer system would have flowed in 1980. Upgradient from the Gulf Trough, where head decline has been minimal, the area where wells would have flowed has changed little, if any (pls. 12, 13).

The head-decline map, plate 13, is based on the predevelopment and present-day (1980) potentiometric surfaces of the Upper Floridan aquifer shown on plates 9 and 12, respectively. Points of data used to contour the head-decline map were derived from the differences in head values at the intersections of superposed contours from the potentiometric-surface maps (pls. 9, 12). Interpolated contours from both potentiometric-surface maps were also used to increase the density of data points and to better define the lines of equal decline. The map showing head decline indicates the change that the potentiometric surface has undergone as a result of development, chiefly that of significant declines in the coastal area.

As shown on plate 13, almost the entire study area is encompassed by a line of zero head decline. The location of the inferred line of zero head decline offshore near the estimated position of the freshwater–saltwater interface in the Upper Floridan would indicate that little movement, or in places possibly no movement, of the interface has occurred since development. Little field data are available to support this contention. Head and salinity data are available only from an abandoned Tenneco, Inc., oil-test well and three other exploratory wells in the offshore area (Johnston and others, 1982, fig. 1, p. 12). The interface within the Upper Floridan at the Tenneco, Inc., site about 55 mi offshore from Fernandina Beach, Fla., seems to be transient between the position that would be compatible with the predevelopment heads and the position that would be compatible with present-day heads. This implies that some movement of the interface probably has occurred since development (Johnston and others, 1982, p. 12). Locally, at Brunswick, Ga., Fernandina Beach, Fla., and St Marys, Ga., saltwater intrusion into the Floridan aquifer system has occurred, indicating some vertical component of movement of the interface (fig. 14).

In the northwest part of the study area, the upgradient limit of head decline (line of zero head decline) lies along the Gulf Trough. Because the trough impedes the downgradient flow of water through the aquifer, it similarly limits the upgradient expansion of head decline. Head decline in the area upgradient from the trough has been negligible because the trough limits the

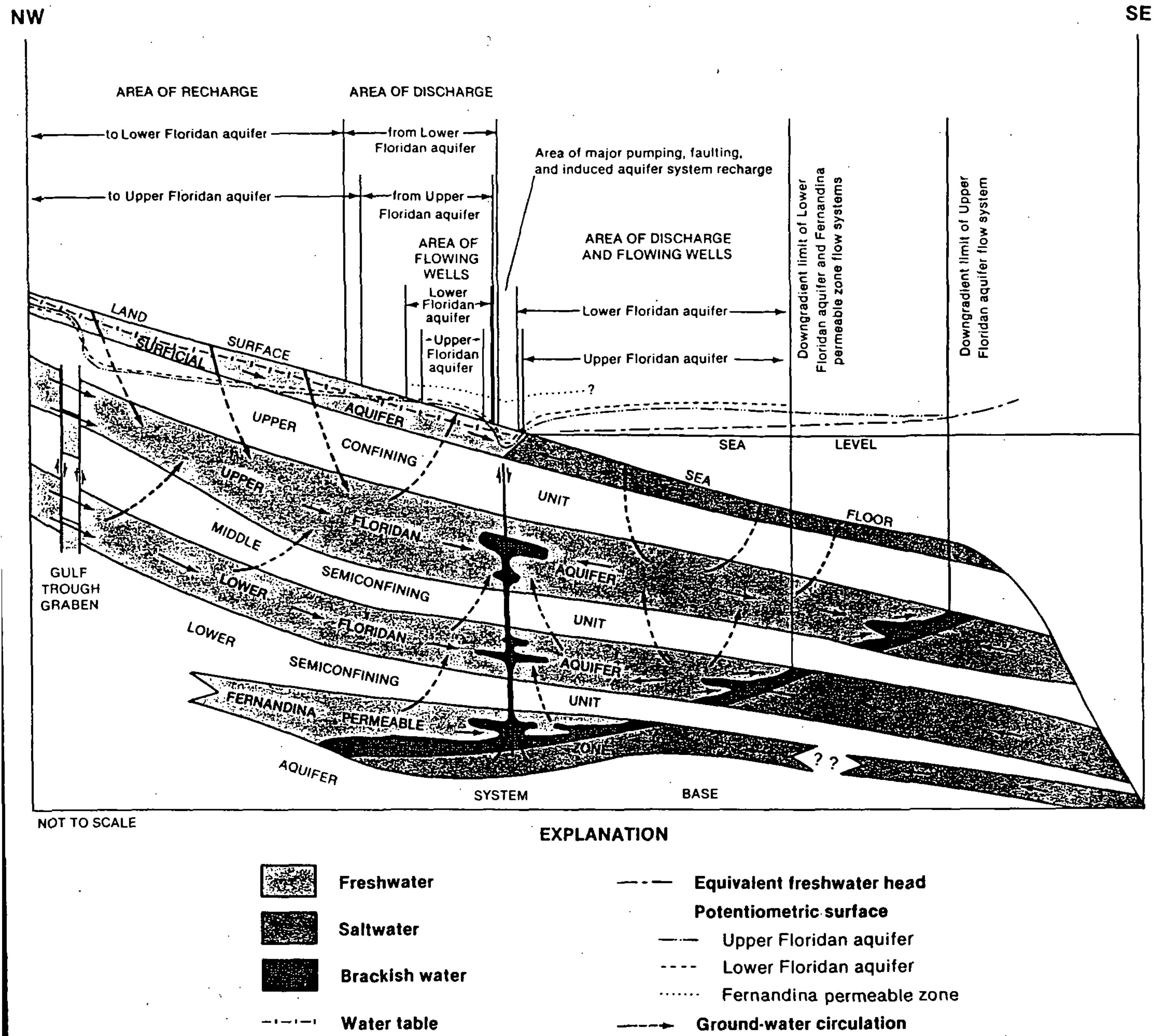


FIGURE 14.—Conceptual model of the present-day (1980) flow system for the Floridan aquifer system from the Gulf Trough in the northwest to the offshore area in the southeast.

expansion of head decline, and because of high rates of recharge and low rates of ground-water withdrawal in the area. An observation well (21T1) near Dexter (the outcrop area) in western Laurens County, Ga., indicates marked seasonal and climatic fluctuations but shows no long-term decline for the period 1964–82 (fig. 15; well location shown on pl. 13). Locally, small declines in head probably have occurred in municipal pumping centers upgradient from the trough, although the extent is unknown because of a lack of data.

Head decline in the area of the trough ranges from little or none at its upgradient side, to 15 to 30 ft at its downgradient side. Locally, head declines are probably greater within areas of the trough having lower transmissivities and moderate ground-water withdrawals. Observation wells in Vidalia, Toombs County (26R1), and Uvalda, Montgomery County (25Q1), within the graben system of the Gulf Trough, indicate head declines of about 1 ft/yr since 1974 and 1966, respectively (fig. 15; well locations shown on pl. 13).

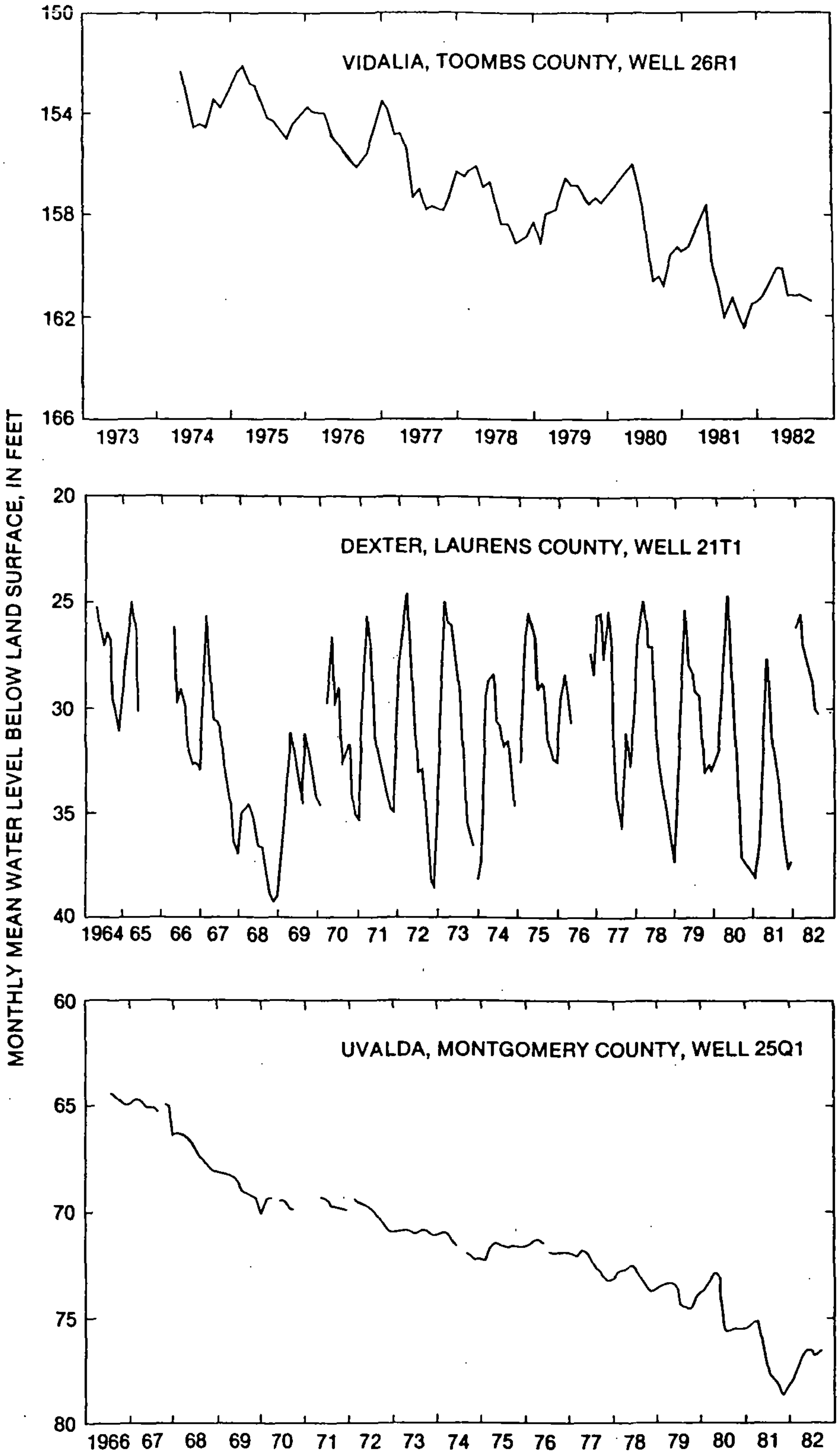


FIGURE 15.—Long-term water-level fluctuations in the Upper Floridan aquifer in Toombs, Laurens, and Montgomery Counties, Ga.

Recharge to the Upper Floridan near Valdosta, Ga., Beaufort, S.C., and Keystone Heights, Fla., limits the head decline near those areas caused by pumping throughout the study area (pl. 13). Heads in the aquifer near the areas of Valdosta, Ga., Beaufort, S.C., and Keystone Heights, Fla., showed seasonal fluctuations in response to precipitation but almost no long-term decline. The water-level trend in the Upper Floridan aquifer in the Valdosta area is closely related to precipitation and streamflow because of the direct recharge of the Upper Floridan by the Withlacoochee River. This relation, shown in figure 16, uses streamflow data from the nearby Alapaha River at Statenville, as data are not available for the Withlacoochee River in the area. Locations of the observation well and the precipitation and streamflow stations are shown on plate 13.

Head decline in the Upper Floridan along the southwestern boundary of the study area has caused significant lateral flow across the boundary that did not exist before development. Some head decline also occurred along the southern boundary of the study area where water in the Upper and Lower Floridan aquifers flowed out of the study area prior to development.

The prominent cones of head decline at Savannah, Brunswick, and Jesup, Ga., have overlapped and produced a large area of head decline that encompasses the three pumping centers. This area is defined by the 30-ft line of equal head decline shown on plate 13. This area and the nearby deep cone of head decline at St Marys, Ga., and Fernandina Beach, Fla., are separated by an area of minimal head decline in Camden County, Ga. This minimal head decline and lack of overlapping of the two closely spaced, deep cones seems to be anomalous when compared with the overlapping cones at Savannah, Jesup, and Brunswick, Ga. Comparison of the maps showing transmissivity (pl. 8) and water-level decline (pl. 13) indicates that a relation exists between transmissivity distribution and water-level decline in the area between Brunswick, Ga., and Fernandina Beach, Fla. Relatively, the transmissivity of the Upper Floridan at Brunswick is large, is substantially less along the Glynn–Camden County line, is largest in Camden County, and is lowest at Fernandina Beach. This distribution of transmissivity, primarily the alignment of low values that acts as a permeability barrier along the Glynn–Camden County line, is probably responsible for the separation of the cones of water-level decline at Brunswick and Fernandina Beach. Simulation supports this hypothesis. In addition, unusually high upward leakage from the Lower Floridan into the Upper Floridan near the south end of Brunswick, Ga., could also produce the 1980 potentiometric surface and water-level decline in the areas of Brunswick, and St Marys, Ga., and Fernandina Beach, Fla., shown on plates 12 and 13, respectively. The upward-leakage hypothesis also is supported by field evidence and by simulation.

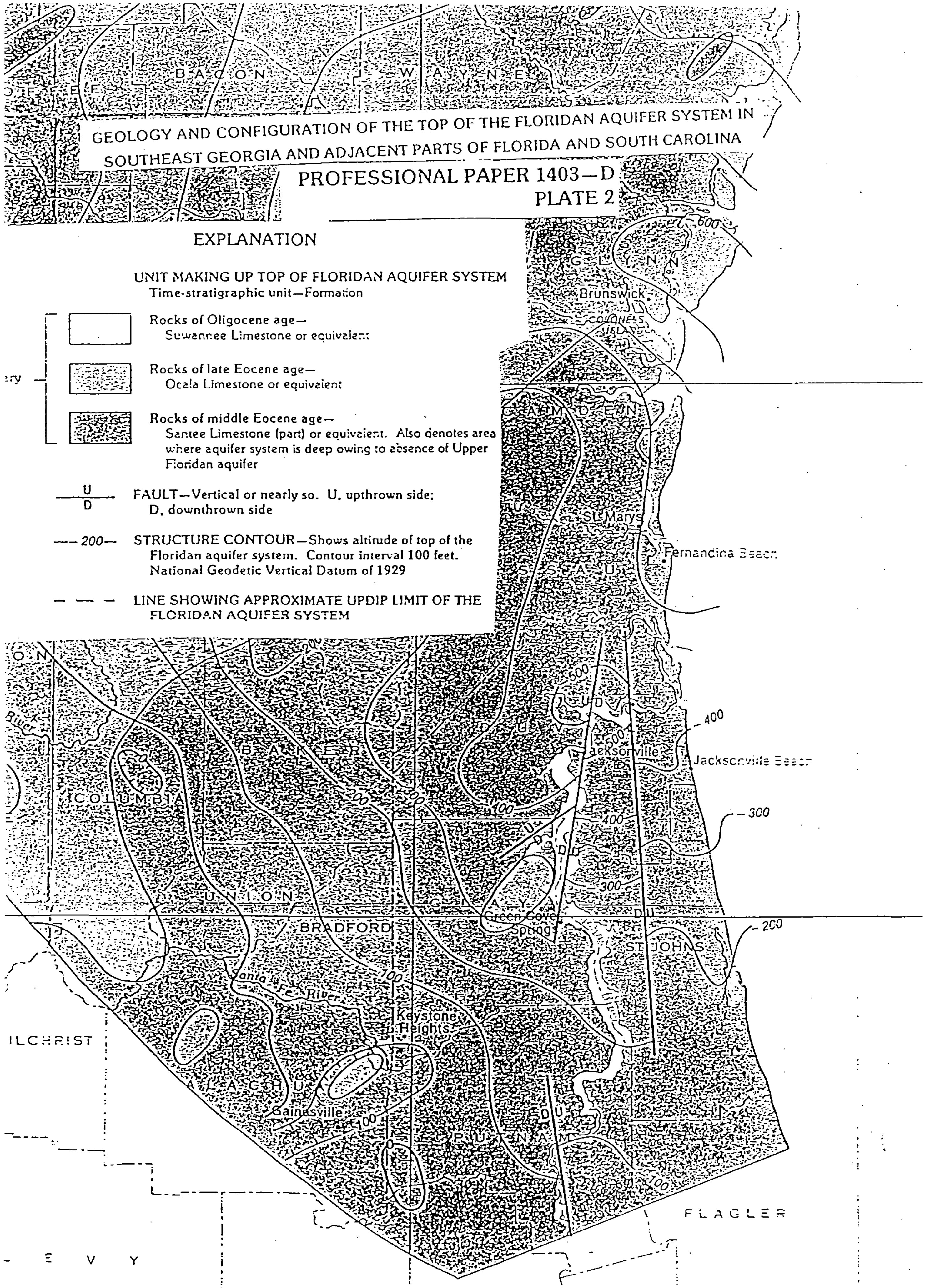
Long-term water-level declines in three observation wells within the cone of depression at Savannah are shown in figure 17. On the basis of the estimated predevelopment potentiometric surface shown on plate 9, the water level in the vicinity of the three observation wells was probably about 30 ft above land surface prior to development. Thus, the water level has declined an estimated 110 to 170 ft at the three observation wells since development began in the 1880's. In Savannah, gradual increases in municipal and industrial pumping caused the water level to decline, with periods of accelerated pumping producing the steeper declines shown in figure 17. During the fifties and early sixties, the water level declined rapidly in response to accelerated pumping. However, since the sixties the water-level decline has leveled off because of stabilized pumping rates (fig. 17).

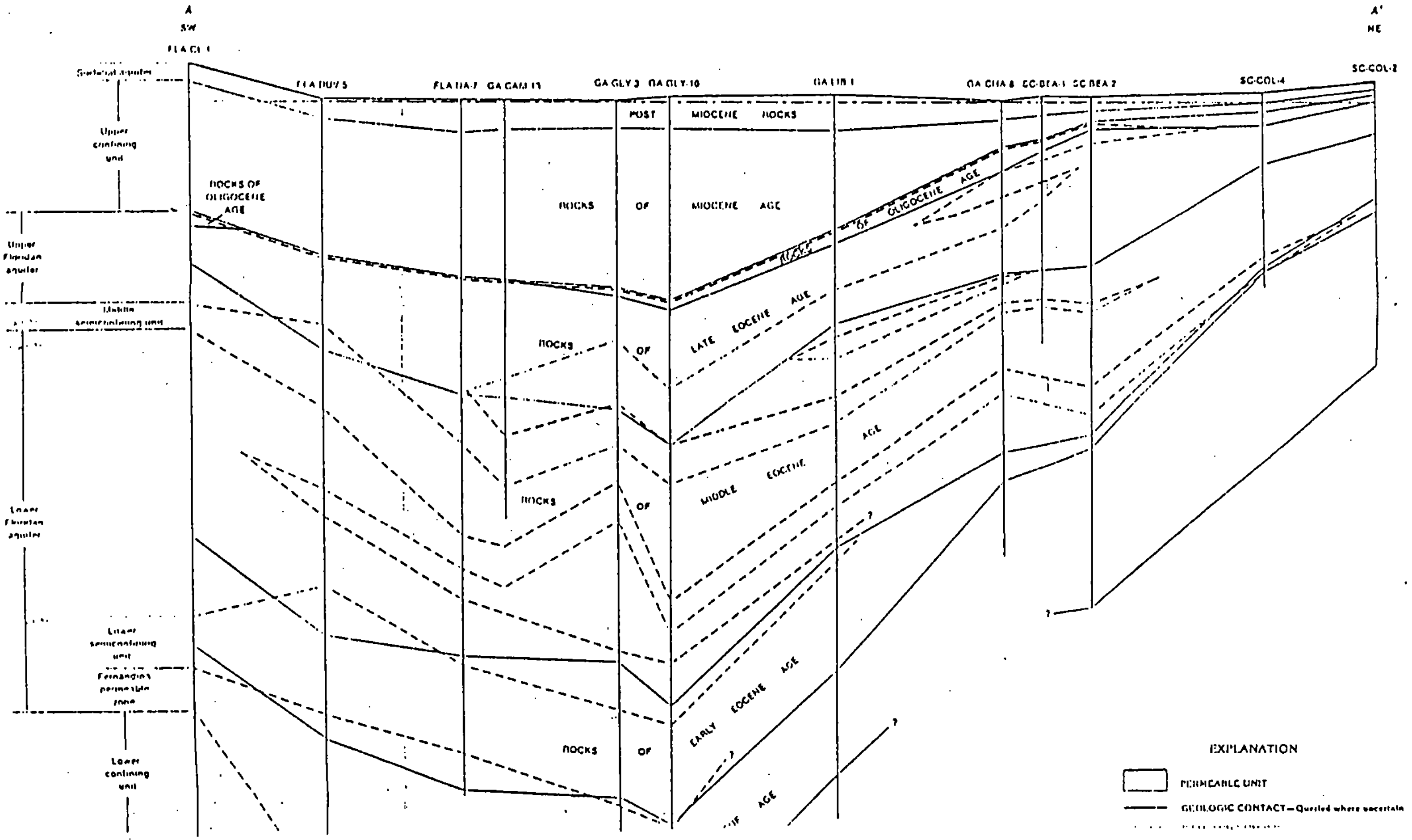
Typical water-level trends in wells within the cones of depression at Brunswick, Ga., and Fernandina Beach, Fla., are shown in figure 18. Prior to development, the water levels in the vicinity of the wells were about 50 to 55 ft above land surface at Brunswick, and about 42 ft above land surface at Fernandina Beach. In both areas, the water level has declined to below land surface, owing mostly to industrial pumping. At Fernandina Beach, the aquifer has apparently reached equilibrium. At Brunswick, the water level continues to decline at a slow rate in well 33H133 near the center of pumping. However, other wells in the Brunswick area farther from pumping have shown nearly no decline during the past 10 years.

LAND SUBSIDENCE

As a result of water-level decline in the Floridan aquifer system in response to ground-water withdrawal, land subsidence has occurred in the area of Savannah, Ga. (Davis, Small, and Counts, 1963; Davis, Counts, and Holdahl, 1976). First, it should be noted that the subsidence at Savannah documented through 1975 was not significant enough to be recognized as an engineering problem, and would probably have gone undetected without precise leveling. Second, this subsidence should not be confused with crustal movements of regional scale, such as that reported by Holdahl and Morrison (1974) and Brown and Oliver (1976), or with coastal submergence as reported by Wait (1968).

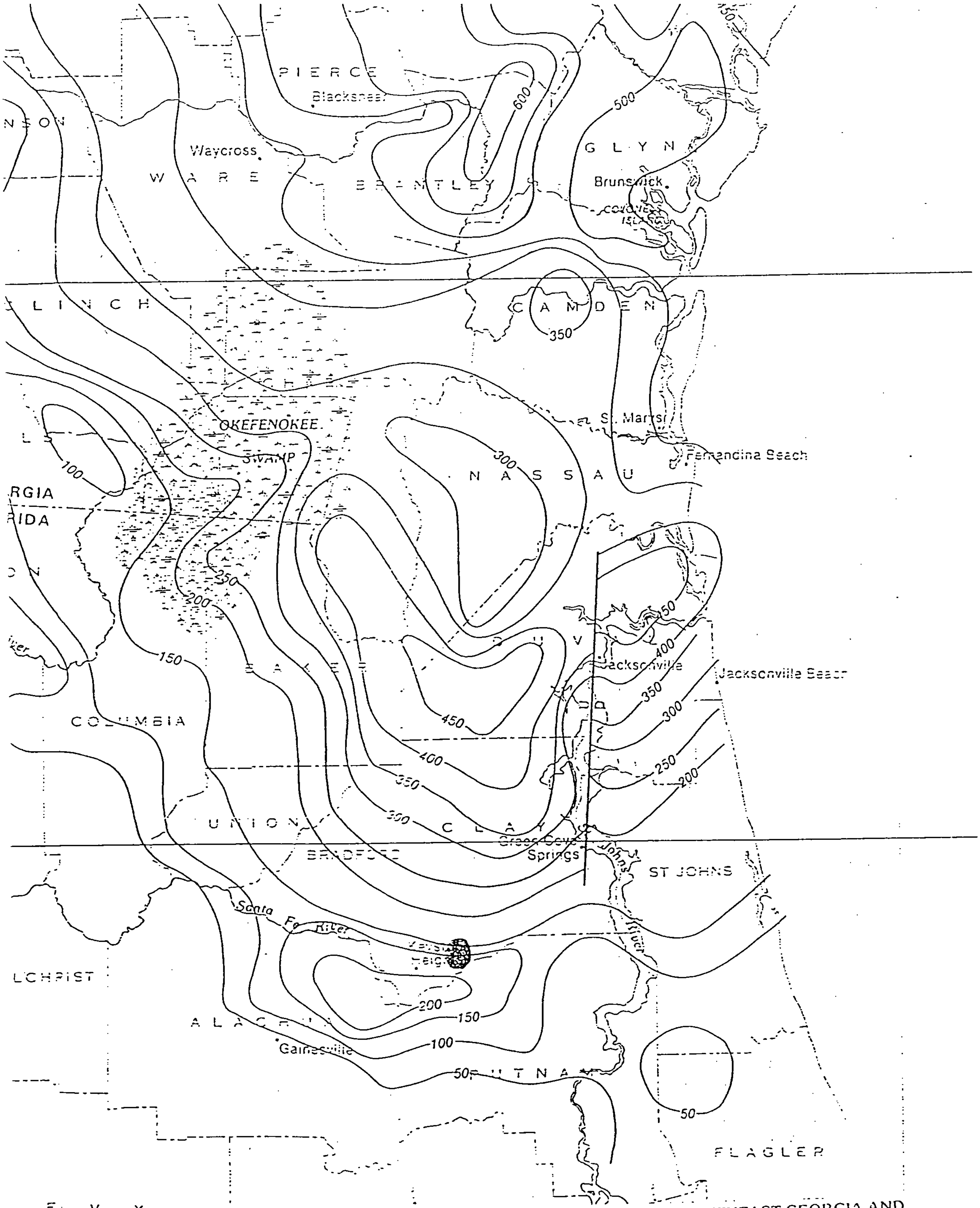
Precise leveling in 1918, 1933, 1935, and 1955 indicated that subsidence of as much as 0.33 ft had occurred in the Savannah area, mostly since 1933 (Davis, Counts, and Holdahl, 1976, p. 350). By 1955, an area of


GEOLOGY AND CONFIGURATION OF THE TOP OF THE FLORIDAN AQUIFER SYSTEM IN SOUTHEAST GEORGIA AND ADJACENT PARTS OF FLORIDA AND SOUTH CAROLINA
PROFESSIONAL PAPER 1403—D
PLATE 2
EXPLANATION
UNIT MAKING UP TOP OF FLORIDAN AQUIFER SYSTEM
Time-stratigraphic unit—Formation
Rocks of Oligocene age—
Suwannee Limestone or equivalent
Rocks of late Eocene age—
Ocala Limestone or equivalent
Rocks of middle Eocene age—
Santee Limestone (part) or equivalent. Also denotes area where aquifer system is deep owing to absence of Upper Floridan aquifer
FAULT—Vertical or nearly so. U, upthrown side; D, downthrown side
—200— STRUCTURE CONTOUR—Shows altitude of top of the Floridan aquifer system. Contour interval 100 feet. National Geodetic Vertical Datum of 1929
LINE SHOWING APPROXIMATE UPDIP LIMIT OF THE FLORIDAN AQUIFER SYSTEM
BACON
WAYNE
Brunswick
CAMDEN
St Marys
Fernandina Beach
NASSAU
BAKER
DUVAL
Jacksonville
Jacksonville Beach
COLUMBIA
UNION
BRADFORD
CLAY
Green Cove Springs
ST JOHNS
Santa Fe River
Keystone Heights
ALACHUA
Gainesville
PUTNAM
GILCHRIST
LEVY
FLAGLER



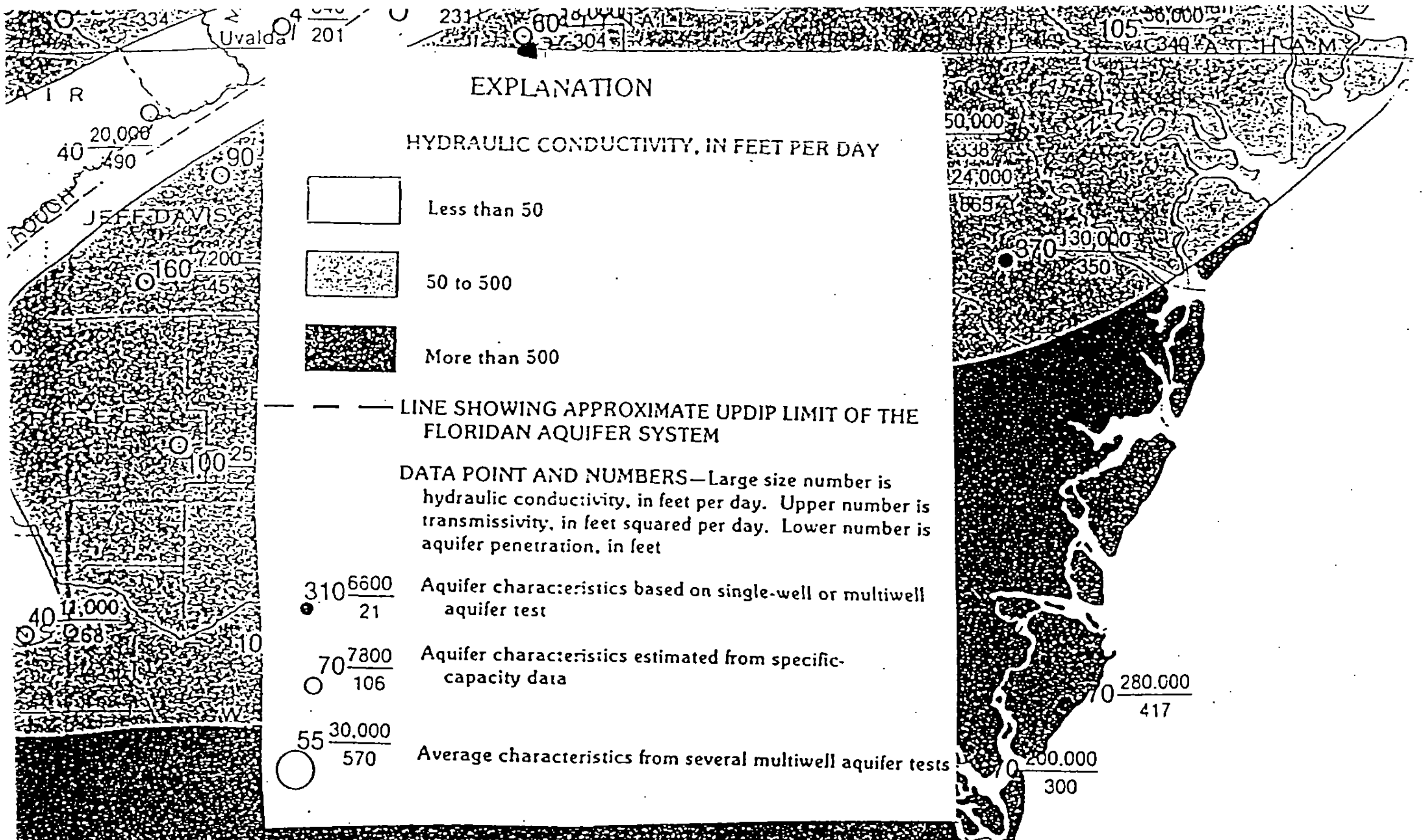
GENERALIZED HYDROGEOLOGIC SECTION SHOWING FLORIDAN AQUIFER SYSTEM ALONG THE ATLANTIC COAST, NORTHEAST FLORIDA TO SOUTHERN SOUTH CAROLINA

PROFESSIONAL PAPER 1403—D
PLATE 4

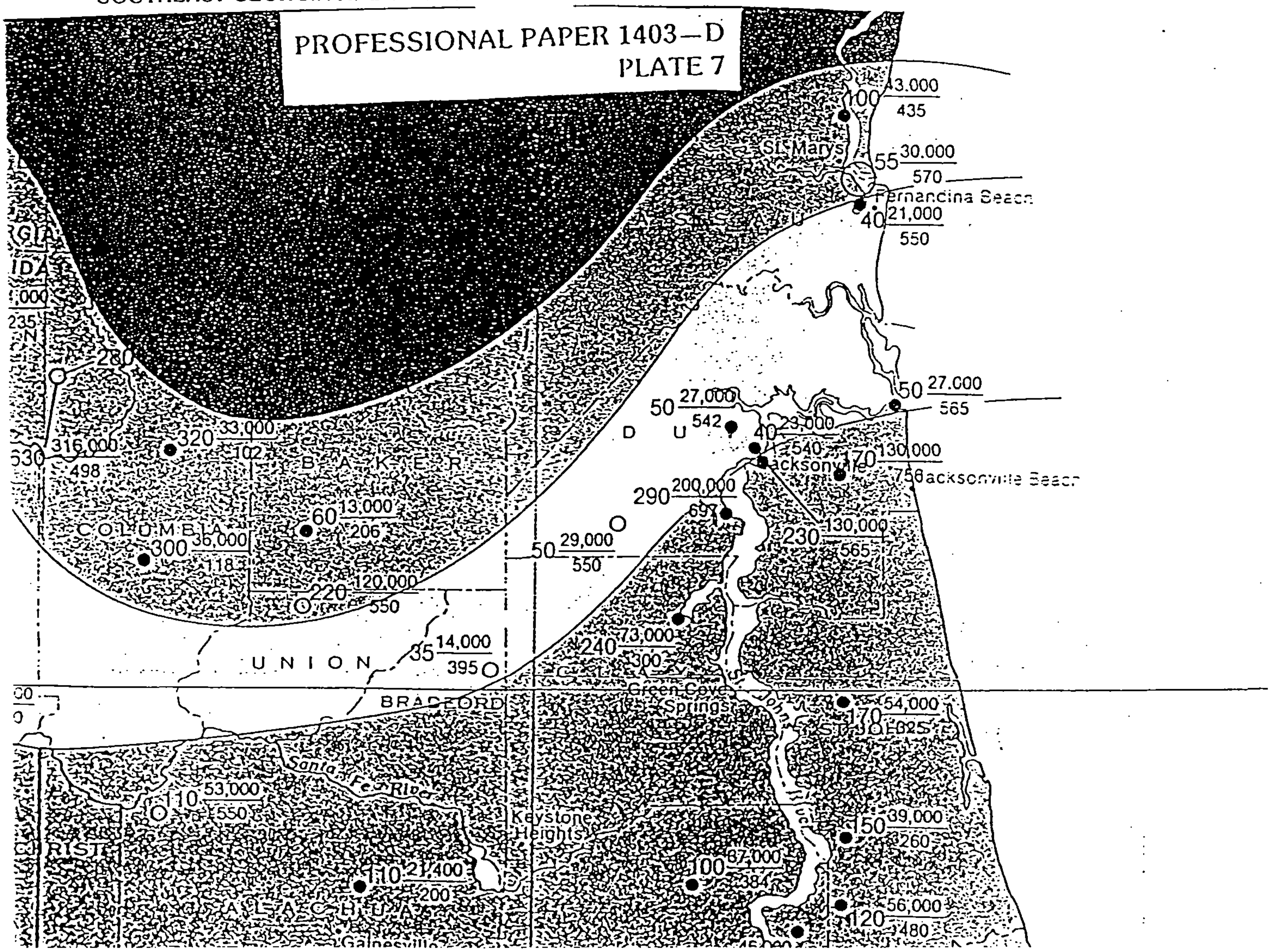


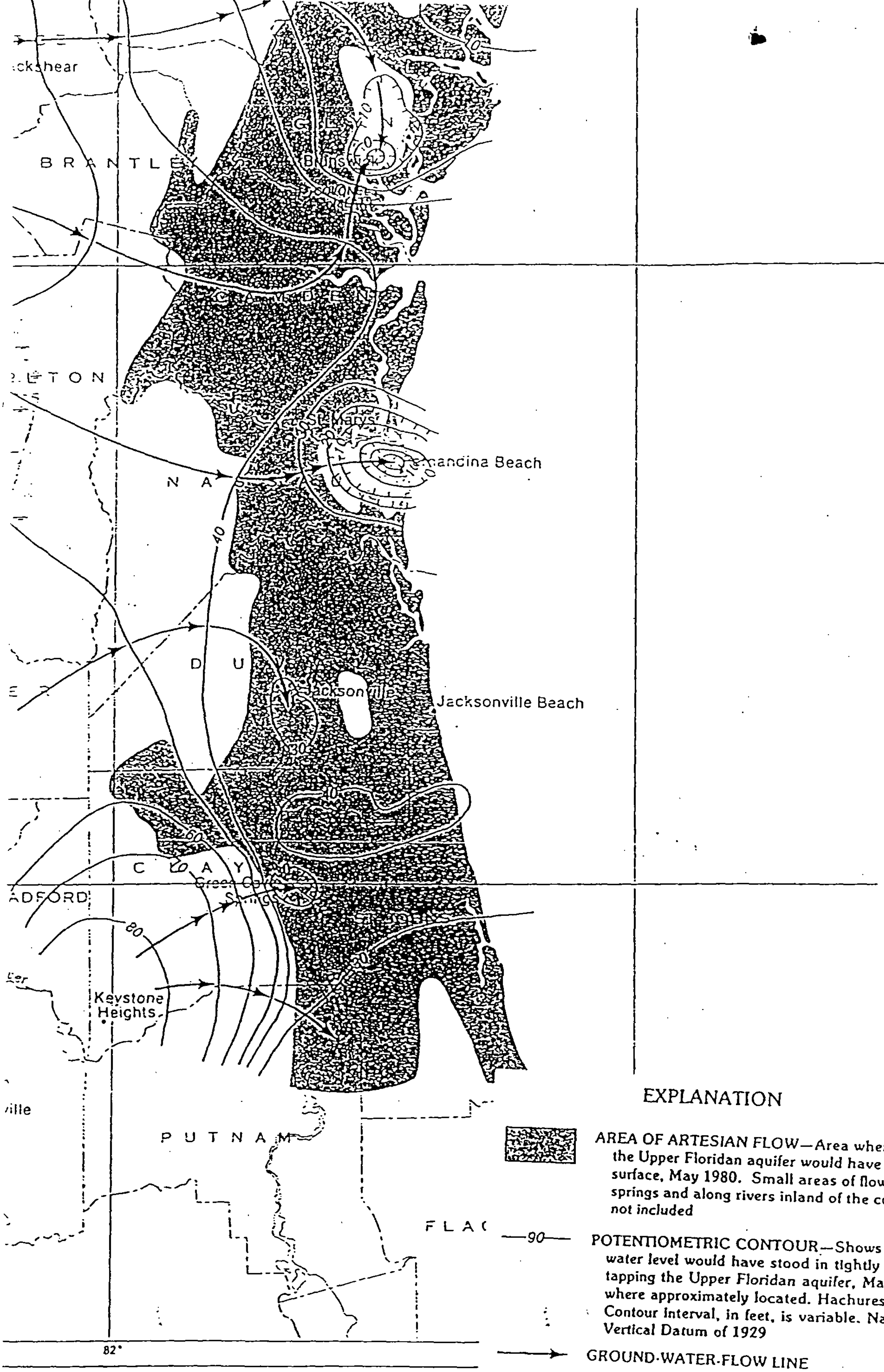
ICKNESS OF THE UPPER CONFINING UNIT OF THE FLORIDAN AQUIFER SYSTEM IN SOUTHEAST GEORGIA AND ADJACENT PARTS OF FLORIDA AND SOUTH CAROLINA

PROFESSIONAL PAPER 1403—D
PLATE 6



D VALUES OF HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY OF THE UPPER FLORIDAN AQUIFER IN SOUTHEAST GEORGIA AND ADJACENT PARTS OF FLORIDA AND SOUTH CAROLINA





EXPLANATION

AREA OF ARTESIAN FLOW—Area where wells tapping the Upper Floridan aquifer would have flowed at land surface, May 1980. Small areas of flow adjacent to springs and along rivers inland of the coastal area are not included

—90— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells tapping the Upper Floridan aquifer, May 1980. Dashed where approximately located. Hachures indicate depression. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929

→ GROUND-WATER-FLOW LINE

Poter

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PLATE 12

POTENTIOMETRIC SURFACE, AREA OF ARTESIAN FLOW, AND FLOW PATHS FOR THE UPPER FLORIDAN AQUIFER
... AND ADJACENT PARTS OF FLORIDA AND SOUTH CAROLINA, MAY 1980

I AQ

Reference 14

Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

By JAMES A. MILLER

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403–B

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[Plates are in pocket]

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REGIONAL AQUIFER-SYSTEM ANALYSIS

HYDROGEOLOGIC FRAMEWORK OF THE FLORIDAN AQUIFER SYSTEM IN FLORIDA AND IN PARTS OF GEORGIA, SOUTH CAROLINA, AND ALABAMA

By JAMES A. MILLER

ABSTRACT

The Floridan aquifer system of the Southeastern United States is comprised of a thick sequence of carbonate rocks that are mostly of Paleocene to early Miocene age and that are hydraulically connected in varying degrees. The aquifer system consists of a single vertically continuous permeable unit updip and of two major permeable zones (the Upper and Lower Floridan aquifers) separated by one of seven middle confining units downdip. Neither the boundaries of the aquifer system or of its component high- and low-permeability zones necessarily conform to either formation boundaries or time-stratigraphic breaks.

The rocks that make up the Floridan aquifer system, its upper and lower confining units, and a surficial aquifer have been separated into several chronostratigraphic units. The external and internal geometry of these stratigraphic units is presented on a series of structure contour and isopach maps and by a series of geohydrologic cross sections and a fence diagram. Paleocene through middle Eocene units consist of an updip clastic facies and a downdip carbonate bank facies, that extends progressively farther north and east in progressively younger units. Upper Eocene and Oligocene strata are predominantly carbonate rocks throughout the study area. Miocene and younger strata are mostly clastic rocks.

Subsurface data show that some modifications in current stratigraphic nomenclature are necessary. First, the middle Eocene Lake City Limestone cannot be distinguished lithologically or faunally from the overlying middle Eocene Avon Park "Limestone." Accordingly, it is proposed that the term Lake City be abandoned and the term Avon Park Formation be applied to the entire middle Eocene carbonate section of peninsular Florida and southeastern Georgia. A reference well section in Levy County, Fla., is proposed for the expanded Avon Park Formation. The Avon Park is called a "formation" more properly than a "limestone" because the unit contains rock types other than limestone. Second, like the Avon Park, the lower Eocene Oldsmar and Paleocene Cedar Keys "Limestones" of peninsular Florida practically everywhere contain rock types other than limestone. It is therefore proposed that these units be referred to more accurately as Oldsmar Formation and Cedar Keys Formation.

The uppermost hydrologic unit in the study area is a surficial aquifer that can be divided into (1) a fluvial sand-and-gravel aquifer in southwestern Alabama and westernmost panhandle Florida, (2) limestone and sandy limestone of the Biscayne aquifer in southeastern peninsular Florida, and (3) a thin blanket of terrace and fluvial sands elsewhere. The surficial aquifer is underlain by a thick sequence of fine clastic rocks and low-permeability carbonate rocks, most of which are part of the middle Miocene Hawthorn Formation and all of which form the upper confining unit of the Floridan aquifer system. In places, the upper confining unit has been removed by erosion or is breached by sinkholes. Water in the Floridan aquifer system thus occurs under unconfined, semiconfined, or fully confined conditions, depending upon the presence, thickness, and integrity of the upper confining unit.

Within the Floridan aquifer system, seven low permeability zones of subregional extent split the aquifer system in most places into an Upper and Lower Floridan aquifer. The Upper Floridan aquifer, which consists of all or parts of rocks of Oligocene age, late Eocene age, and the upper half of rocks of middle Eocene age, is highly permeable. The middle confining units that underlie the Upper Floridan are mostly of middle Eocene age but may be as young as Oligocene or as old as early Eocene. Where no middle confining unit exists, the entire aquifer system is comprised of permeable rocks and for hydrologic discussions is treated as the Upper Floridan aquifer.

The Lower Floridan aquifer contains a cavernous high-permeability horizon in the lower part of the early Eocene of southern Florida that is called the Boulder Zone. A second permeable unit that is cavernous in part, herein called the Fernandina permeable zone, occurs in the lower part of the Lower Floridan in northeastern Florida and southeastern Georgia. Both these permeable zones are overlain by confining units comprised of micritic limestone. The confining unit that overlies the Boulder Zone is of subregional extent and is mapped as a separate middle confining unit within the Lower Floridan.

Major structural features such as the Southeast and Southwest Georgia embayments, the South Florida basin, the Gulf Coast geosyncline, and the Peninsular arch have had a major effect on the thickness and type of sediment deposited in the eastern gulf coast. The effects of smaller structures are also evident. For example, the Gilbertown-Pickens-Pollard fault system in Alabama locally forms the updip limit of the Floridan aquifer system. The series of grabens that comprise the Gulf Trough of central Georgia serves as a low-permeability barrier to ground-water flow there. These Gulf Trough faults have downdropped low-permeability rocks opposite permeable limestones to create a damming effect that severely retards ground-water movement across the fault system. Their

effect can be seen on potentiometric surface maps of the aquifer system. Other small-displacement faults in peninsular Florida do not appear to affect the regional flow system because there is no apparent change in the permeability of the rocks that have been juxtaposed by fault movement.

Variations in permeability within the Floridan aquifer system result from a combination of original depositional conditions, diagenesis, large- and small-scale structural features, and dissolution of carbonate rocks or evaporite deposits. Local permeability variations are accordingly more complex than the generalized regional portrayal presented in this report.

INTRODUCTION

PURPOSE AND SCOPE

In 1977 the U.S. Geological Survey began a nationwide program to study a number of the regional aquifers that provide a significant part of the country's water supply. This program, termed the Regional Aquifer-System Analysis (RASA), is discussed in detail by Johnston and Bush (1985). In brief, the general objectives of each RASA study are (1) to describe the ground-water system as it exists today and as it existed before development, (2) to analyze changes between present and predevelopment systems (3) to integrate the results of previous studies dealing with local areas or discrete aspects of the system, and (4) to provide some capability for evaluating the effects (particularly the hydraulic effects) that future ground-water development will have on the system. These objectives can best be met by a regional-scale digital computer simulation of the aquifer system, supplemented where necessary by more detailed subregional simulations and by interpretations of the distribution of observed water-quality variations. Because of its importance as a source of ground-water supply and because of various problems that have arisen from intensive use, the Floridan aquifer system of the Southeastern United States was among the first regional aquifer systems chosen for study.

The Floridan aquifer system is comprised of carbonate rocks of Tertiary age and includes but is not limited to the sequence of rocks generally called the "Floridan aquifer" in Florida and the "principal artesian aquifer" in Georgia. Tertiary limestones also yield water, locally in appreciable quantities, in parts of southwestern South Carolina and southeastern Alabama. These limestones are included in the Floridan aquifer system in this report. The approximate areal extent of the aquifer system is shown in figure 1. The system includes rocks of Paleocene to early Miocene age that combine to form a vertically continuous carbonate sequence that is hydraulically connected in varying degrees. Very locally, in the Brunswick, Ga., area, beds assignable to the uppermost part of the Upper Cretaceous System are included in the Floridan aquifer system. Over much of the area where the aquifer system crops out, it consists of one vertically continuous permeable unit. Downdip, the aquifer system generally consists of two major permeable zones, herein called the Upper Floridan aquifer and the Lower Floridan aquifer, that are separated by less-permeable rock of highly variable hydraulic properties (very leaky to virtually nonleaky). Hydraulic conditions for the aquifer system vary from confined to unconfined, depending upon whether the argillaceous middle Miocene and younger rocks that form the upper confining unit of the system have been breached or removed by erosion.

As one of several chapters of a Professional Paper describing different aspects of the Floridan aquifer system and discussing the results of computer simulations, this report presents the hydrogeologic framework of the aquifer system as determined from subsurface geologic and hydrologic data. The objectives of this part of the study were:

1. To identify the aquifer system regionally in terms of the geologic and hydrologic units that comprise it and to define its extent.

2. To delineate regional permeability variations within the aquifer system, primarily on the basis of rock composition and texture and, to a lesser extent, on the development of secondary (solution) porosity.

3. To establish the influence of geologic structure and of variation in rock type on the ground-water flow pattern of the aquifer system.

4. To identify and map regional stratigraphic units and to establish a correlation framework between surface and subsurface geologic units.

5. To determine variations in the geometry and physical makeup of the aquifer system that affect either hydraulic parameters or the water quality of the system.

PREVIOUS WORK

Numerous reports have been published, chiefly by the U.S. Geological Survey and State geological surveys, that discuss various aspects of the geology and ground-water resources of the study area. For the most part, the scope of these reports is local or subregional. Extensive lists of publications on the geology and hydrology of the Floridan aquifer system are contained in reports by Murray (1961), Stringfield

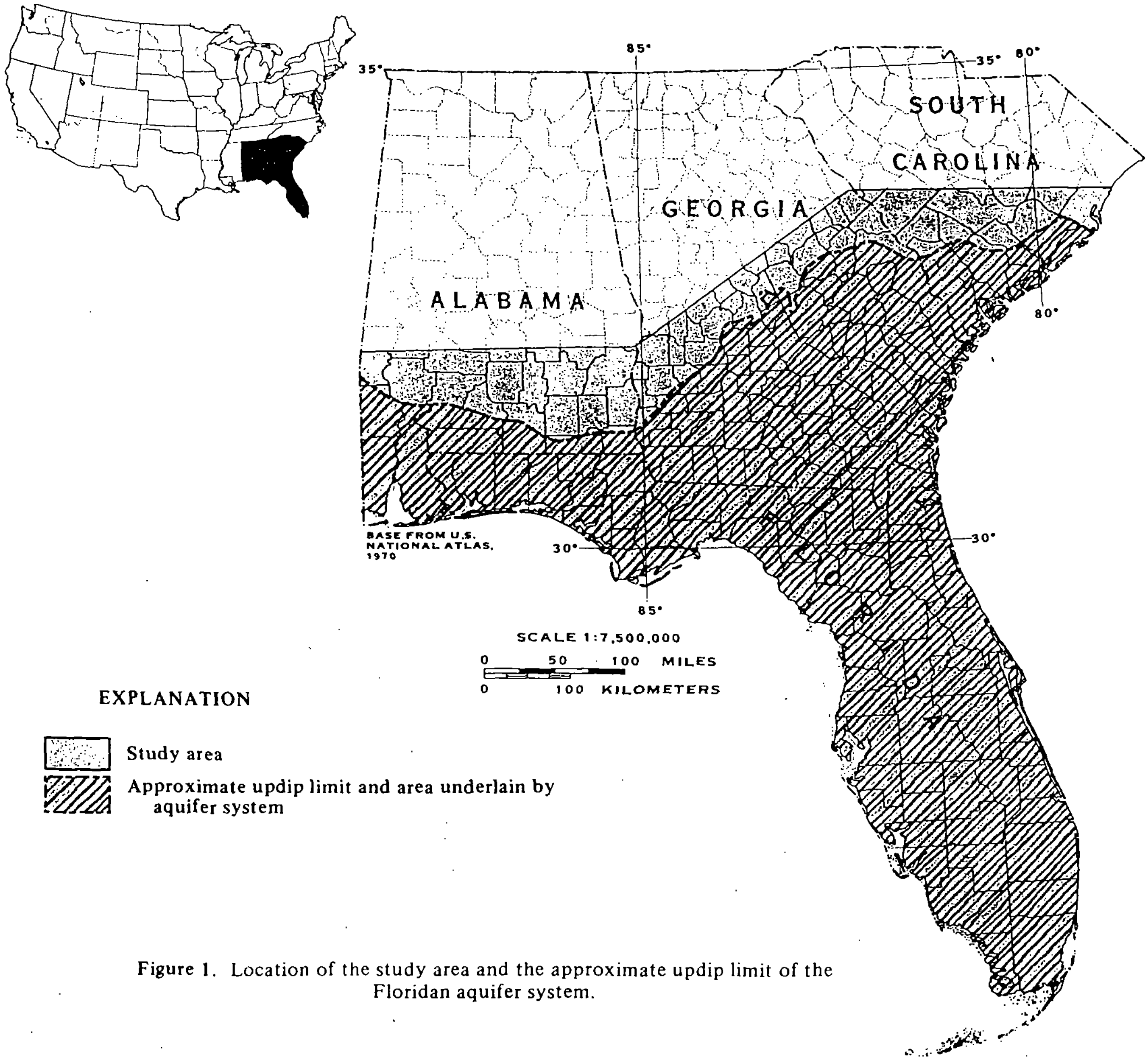


Figure 1. Location of the study area and the approximate updip limit of the Floridan aquifer system.

(1966), Braunstein (1970, 1976), Heath and Conover (1981), and Krause (1982). Reports dealing with the regional surface and subsurface geology of the Tertiary rocks in the report area include those of Applin and Applin (1944, 1964), Chen (1965), Cooke (1943, 1945), Copeland (1968), Herrick (1961), Herrick and Vorhis (1963), LaMoreaux (1946), Maher (1965, 1971), Maher and Applin (1968), Murray (1961), Puri (1953b, 1957), Puri and Vernon (1964), Randazzo and others (1977), and Randazzo and Hickey (1978). Reports that discuss regional aspects of ground water in the Floridan aquifer system have been written by Callahan (1964), Cederstrom and others (1979), Hanshaw and others (1971), Hayes (1979), Parker and others (1955), Stephenson and Veatch (1915), Stringfield (1936, 1966), and Warren (1944).

In places, the lithologic differences between strata that form the Floridan aquifer system are subtle. Accordingly, the microfauna contained in these strata have been used by some workers to establish stratigraphic subdivisions within the system. Reports on the microfauna of the Tertiary limestones include those of Applin and Jordan (1945), Cole (1938, 1941, 1942, 1944, 1945), Cushman (1935, 1951), Cushman and Ponton (1932), Levin (1957), and Loeblich and Tappan (1957).

ACKNOWLEDGMENTS

Appreciation is due several organizations and individuals who contributed data and suggestions during the course of the study. State geologists and members of their staffs who furnished well locations and geophysical logs and made libraries of well cuttings available for examination include C. W. Hendry (Chief) and T. M. Scott, R. W. Hoenstine, and Walter Schmidt of the Florida Bureau of Geology; W. H. McLemore (State Geologist) and P. H. Huddleston of the Georgia Geologic Survey; and P. E. LaMoreaux (former State Geologist) and C. W. Copeland (Chief Geologist) of the Geological Survey of Alabama. Personnel of the Northwest Florida, Suwannee River, and St. Johns River Water Management Districts provided well locations and some geophysical logs.

Carol Gelbaum, formerly of the Georgia Geologic Survey, provided extensive information on the lithology, paleontology, and water-bearing characteristics of the rocks in the Gulf Trough area of the central Georgia coastal plain and did the initial drafting of the cross sections and fence diagram used in this report.

U.S. Geological Survey colleagues who contributed to the investigation include M. E. Davis, J. G. Newton, and C. A. Pascale (Alabama); D. P. Brown, J. D. Fretwell, H. G. Healy, G. H. Hughes, G. W. Leve, A. S. Navoy, Horace Sutcliffe, Jr., D. F. Tucker, John Vecchioli, and F. A. Watkins (Florida); H. E. Gill, R. W. Hicks, and S. E. Matthews (Georgia); and R. N. Cherry and P. W. Johnson (South Carolina).

P. A. Thayer, formerly of the University of North Carolina at Wilmington, studied the carbonate mineralogy and petrography of cores collected during test-hole drilling conducted for this study. Valerie McCollister did the preliminary drafting of the cross sections and other related illustrations.

METHOD OF STUDY

APPROACH

The study area (fig. 1) extends from the southern part of the Atlantic Coastal Plain, a geologic province that has been affected primarily by compressional tectonics (Brown and others, 1972) westward into the eastern part of the Gulf Coastal Plain, which has been affected predominantly by gravity tectonics (Murray, 1961), and southward to encompass the Florida platform, which is underlain by a thick sequence of shallow-water platform-type carbonate rocks. Rapid and complex facies changes occur in the area, especially in places where carbonate rock grades laterally into clastic rock. Correlation between clastic and carbonate units or between surface and subsurface units is at present imprecise in the study area. Accordingly, the stratigraphic units used herein have been delineated in the subsurface and mapped as chronostratigraphic units that may include several formations. Structure contour and isopach maps have been prepared for six such Cenozoic chronostratigraphic units. These maps, along with eight cross sections and a fence diagram, show the geometry of and relations between the mapped units. Altitudes on the maps and cross sections and on the fence diagram are related to the National Geodetic Vertical Datum (NGVD) of 1929, a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada. The NGVD of 1929 was formerly called mean sea level. For convenience of usage, however, the NGVD of 1929 is referred to as sea level in the text and on the figures and plates in this report.

The top and base of the Floridan aquifer system, as well as the top and base of major permeability variations within the system, commonly coincide with the top of a chronostratigraphic unit or a particular rock type. Such coincidence is not the case everywhere, however. The vertical limits of the aquifer system as mapped for this study represent the top and base of carbonate rocks that are generally highly permeable and that are overlain and underlain by low-permeability material. The low-permeability rock that delineates the system may be either a clastic rock or a carbonate. In places, the permeability contrast between the aquifer system and its upper and lower confining units may exist within a rock unit or a chronostratigraphic unit. For example, in places, the upper part of the Suwannee Limestone of Oligocene age consists of low-permeability micritic limestone underlain by highly permeable limestone comprised largely of pelecypod and gastropod casts and molds that is also part of the Suwannee. In this case, the top of the Floridan aquifer system would be placed at the top of the highly permeable cast-and-mold limestone rather than at the top of the Suwannee. The aquifer system is thus defined on the basis of its permeability characteristics rather than on the basis of lithology. Accordingly, the structure contour map of the top of the Floridan aquifer system presented in this report differs considerably from previously published maps that represent either the top of vertically continuous limestone or the top of a particular geologic horizon, regardless of its permeability. Structure contour maps representing the base of the aquifer system and the base of the upper major permeable zone within it (the Upper Floridan aquifer) were presented for the first time by Miller (1982a, b) in preliminary open-file publications and are reproduced in this report with minor modifications. Isopach maps of the total aquifer system and of the Upper Floridan aquifer are also presented.

Tops and thicknesses of both chronostratigraphic and permeability units were determined in each of 662 wells selected as key data points. The tops and bottoms of both types of units were established on the basis of the lithologic, paleontologic, and hydraulic characteristics of each unit as revealed in certain deep test wells. Geophysical log (chiefly electric log) patterns representative of each stratigraphic and permeability unit were determined, and the units were extrapolated subregionally primarily on the basis of these log patterns and supplementary descriptions of cores and drill cuttings. The mineralogic composition of rock samples from certain test wells was determined primarily by examining the samples with a binocular microscope. Three assumptions were made in extending relatively permeable and impermeable zones: (1) most of the porosity observed in drill cuttings and in core was effective porosity and therefore indicated a relatively permeable rock, (2) high- and low-porosity rocks were expressed on electric logs by different resistivity characteristics, and (3) once the electric log pattern of a zone was established as representing high or low permeability, the permeability of that zone was considered to remain essentially the same forthe geographic area in which the log pattern remained the same.

The locations of the wells that comprise the data network used in constructing the various maps and cross sections are shown on plate 1. On the cross sections (locations also shown on pl. 1) and in the text of the report, each well is designated by an abbreviation that identifies the State and county within which the well is located and a sequential project number within that county. On the cross sections, wells in Florida and Alabama are also located by the section-township-range grid of the Federal System of Rectangular Surveys within which they lie. For the well-numbering system used herein, the State abbreviations are those in common usage. The county abbreviations are as follows:

Alabama

Baldwin	BAL
Clarke	CL
Covington	COV
Escambia	ES
Geneva	GEN
Houston	HO
Mobile	MOB
Monroe	MON

Florida

Alachua	AL
Baker	BA
Bay	BAY
Bradford	BRA
Broward	BRO
Calhoun	CAL
Charlotte	CHA
Citrus	CI
Clay	CL
Collier	COL
Columbia	CO
Dade	DA
DeSoto	DE
Dixie	DIX
Duval	DUV
Escambia	ESC
Flagler	FL
Franklin	FRA
Gadsden	GA
Gilchrist	GIL
Glades	GL
Gulf	GF
Hamilton	HAM
Hardee	HAR
Hendry	HEN
Hernando	HER
Highlands	HI
Hillsborough	HIL
Holmes	HOL
Indian River	IR
Jackson	JX
Jefferson	JEF
Lafayette	LAF
Lake	LK
Lee	LEE
Leon	LN
Levy	LV
Liberty	LIB
Madison	MAD
Manatee	MAN
Marion	MAR
Martin	MTN
Monroe	MON
Nassau	NA
Okaloosa	OKA
Okeechobee	OKE
Orange	OR
Osceola	OS
Palm Beach	PB
Pasco	PAS
Pinellas	PIN
Polk	POL
Putnam	PUT
St. Johns	SJ
St. Lucie	SL
Santa Rosa	SR
Sarasota	SAR
Suwannee	SUW
Taylor	TAY
Union	UN
Volusia	VO
Wakalla	WAK
Walton	WAL
Washington	WAS

Georgia

Appling	AP
Atkinson	AT

Bacon	BAC
Baker	BAK
Ben Hill	BH
Berrien	BER
Brantley	BRA
Brooks	BRO
Bryan	BRY
Bullock	BUL
Burke	BU
Calhoun	CAL
Camden	CAM
Charlton	CHN
Chatham	CHA
Clinch	CLI
Coffee	COF
Colquitt	COQ
Cook	COK
Crisp	CRP
Decatur	DE
Dodge	DOE
Dooly	DO
Dougherty	DOG
Early	EA
Echols	EC
Effingham	EFF
Emanuel	EM
Evans	EV
Glynn	GLY
Grady	GR
Houston	HOU
Irwin	IR
Jeff Davis	JD
Jenkins	JEN
Laurens	LA
Lee	LEE
Liberty	LIB
Long	LO
Lowndes	LOW
McIntosh	MC
Mitchell	MIT
Montgomery	MO
Pierce	PI
Pulaski	PU
Screven	SCR
Seminole	SE
Tattnall	TAT
Telfair	TEL
Terrell	TER
Thomas	THO
Tift	TF
Toombs	TO
Treutlen	TR
Ware	WA
Wayne	WAY
Wheeler	WH
Wilcox	WX
Worth	WOR

South Carolina

Allendale	AL
Bamberg	BAM
Beaufort	BEA
Charleston	CHN
Colleton	COL
Dorchester	DOR
Hampton	HAM
Jasper	JAS

The designation SC-HAM-3, for example, means that the well is located in Hampton County, S.C., and that it is the third well within that county for which data were obtained. In general, wells selected as key wells are those for which geophysical logs are available along with drill cuttings and (or) core.

The tops and thicknesses of the different stratigraphic and permeability units delineated have been tabulated for each of the 662 wells used as control points. The tables are arranged alphabetically by the State and county in which the wells are located. This tabulation has been published as a data report by Miller, (1984) and is available from the Open-File Services Section, Central Distribution Branch, U.S. Geological Survey, P.O. Box 25425, Federal Center, Denver, CO 80025. The well tables are also on file in the office of the Regional Hydrologist, Southeastern Region, Water Resources Division, U.S. Geological Survey, 75 Spring Street, S.W., Atlanta, GA 30303, and are available for examination. The well data are stored in the U.S. Geological Survey computer and may be obtained as a computer printout or as card images from the Automatic Data Section, Office of the Assistant Chief Hydrologist for Scientific Publications and Data Management, Water Resources Division, U.S. Geological Survey, National Center, 12201 Sunrise Valley Drive, Reston, VA 22092.

Most of the key wells used as control points are oil test wells, which are generally the only wells deep enough to penetrate the entire Floridan aquifer system. Oil test wells can be recognized in the well tables by a number accompanying the property owner's name in the "Lease" column. For example, a well whose lease is designated as "#1 Gulf and Western 7-4" is an oil test well. The oil test data were supplemented by data from numerous water wells, particularly those drilled to test the potential for water production from or waste injection into deep zones in the aquifer system. In places where deep well control of any type is sparse, data were used from some of the thousands of shallow water wells in the project area, primarily in mapping the top of the aquifer system. All pertinent offshore well data were examined, although contouring was not extended seaward of the present-day shoreline. Interpretations made from borehole data were extended and supplemented by examination of publicly and privately owned reflection and refraction seismic data, particularly in southern Florida, southeastern Georgia, and offshore.

CORRELATION PROCEDURE

Correlation difficulties always arise in any study of regional scope because of the wide variations in depositional environments and, consequently of rock types that one encounters in mapping geology and permeability distribution over a large area. The present study was no exception. Complex facies changes occur between those parts of the region where mostly carbonate rocks were deposited and those parts that received mostly clastic sediments. Within the areas that are underlain mostly by carbonate rocks, such as the Florida peninsula, thick sequences of limestones were deposited in warm, shallow marine water over long periods of geologic time. Because the same shallow-marine environment persisted in much of Florida throughout Tertiary time, the textural or mineralogic changes in the carbonate rock column may be subtle in places. Diagenetic alteration at many locales has affected the carbonate rocks as much as or more than changes in primary depositional conditions. Also, in much of the Florida peninsula, the same rock type may recur at several horizons in the geologic column because the exact depositional and (or) diagenetic conditions that produced it were repeated several times.

All the preceding factors preclude regional correlation of stratigraphic units on the basis of lithology alone. They also account in large part for some of the uncertainty in correlation between surface and subsurface units in the project area and for the controversy that surrounds some published correlations. The existing stratigraphic correlation framework used in the study area is twofold, consisting of (1) detailed correlations involving many formation names in outcrop (largely clastic rock) areas and based primarily on lithology and supplemented by macropaleontology and (2) generalized, regionally extensive correlations involving only a few "formation" names in the deep subsurface (largely carbonate rock) areas and based primarily on micropaleontology. The subsurface correlations were made and many of the subsurface Tertiary "formations" were named at a time when only a few widely scattered deep wells existed and when no uniform procedure for naming geologic units was followed. The lithologic differences (often subtle) between such "formations," some of which were named because they contained a unique microfauna, are in many cases confined to a local area. The rock type supposedly characteristic of a given "formation" in a given well can often be found in a nearby well at a completely different stratigraphic horizon.

A worker attempting to make regional correlations in a particular study area is thus faced with the problem of trying to tie together well-defined surface or near-surface rock-stratigraphic units with nebulous subsurface biostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983) through an intervening area of complex facies change. Neither the surface nor the subsurface correlation framework traditionally used is adequate to describe the physical (or biologic) situation that exists in the rocks.

The equivalency of surface and subsurface geologic units in a project area can best be established by mapping time-rock or chronostratigraphic units. The units chosen for mapping in this report correspond mostly to the series within the Tertiary System or to parts of such series. Chronostratigraphic units include rocks deposited during a particular span of geologic time, regardless of whether they have the same lithology everywhere. The upper and lower boundaries of the time-rock units mapped in this report coincide with changes in rock type that occur in specific wells from which cores and (or) reliable drill cuttings are available. The different chronostratigraphic units delineated were then extended to other wells primarily on the basis of geophysical (mostly electric) log patterns. As correlations of a chronostratigraphic unit are extended laterally over a wide area, the rock types included in that unit may change, and the log pattern of the unit will also change. Different strata are grouped with a given chronostratigraphic unit if they can be shown to represent a logical lateral facies change or to be isochronous with other strata included in the unit elsewhere.

Because the units mapped in this report are time-rock units, their upper and lower boundaries are determined in part by the fauna (chiefly microfauna) that they contain. In general, the vertical range of the microfossils considered characteristic of a given time-rock unit coincides with the vertical boundaries of the various rock types assigned to that unit. Obvious exceptions are reworked or caving faunas. Benthic and planktic Foraminifera, supplemented by Ostracoda, were used chiefly for correlation. The different species considered characteristic of a particular time-rock unit in the study area are listed in table 1, along with a letter-number designation assigned to each species. On the cross sections in this report, the highest occurrence of a given characteristic species identified from a given well is shown by plotting the letter-number code for that species alongside the well column. All of the species that are considered in this report to be time diagnostic are illustrated elsewhere and are accordingly not illustrated herein. The principal reference used for identification, taxonomy, and stratigraphic range determination for the planktic Foraminifera was a paper by Stainforth and others (1975), supplemented by reports by Postuma (1971) and Berggren (1977).

GEOLOGY

REGIONAL SETTING

The Coastal Plain province of the Southeastern United States is underlain by a thick sequence of unconsolidated to semiconsolidated sedimentary rocks that range in age from Jurassic to Holocene. These sediments thicken seaward in the study area from a featheredge where they crop out against older metamorphic and igneous rocks of the Piedmont and Applachian provinces to a maximum penetrated thickness of more than 21,100 ft in Mobile County in southern Alabama. In southern Florida, the thickness of Coastal Plain sediments probably exceeds 25,000 ft; however, the maximum thickness penetrated there as of this writing (1984) is slightly more than 18,600 ft. Coastal Plain rocks generally dip gently toward the Atlantic Ocean or the Gulf of Mexico, except where they are warped or faulted on a local to subregional

Table 1.—*Microfauna characteristic of the several chronostratigraphic units in the study area, and their cross-section designations*

Cross-section designation	Fossil
	Miocene Series
M-1	*Amphistegina chipolensis* Cushman and Ponton
M-2	*Amphistegina lessoni* d'Orbigny
M-3	*Bolivina floridana* Cushman
M-4	*Bolivina marginata multicostata* Cushman
M-5	*Elphidium chipolensis* (Cushman)
M-6	*Sorites* sp.
M-7	*Aurila conradi* (Howe and McGuirt)
M-8	*Hemicythere amygdula* Stephenson
	Oligocene Series
OL-1	*Pararotalia byramensis* Cushman
OL-2	*Miogypsina* sp.
OL-3	*Pulvinulina mariannensis* Cushman
OL-4	*Robulus vicksburgensis* (Cushman) Ellisor
OL-5	*Palmula caelata* (Cushman) Israelsky
OL-6	*Globigerina selli* (Borsetti)
OL-7	*Lepidocyclina leonensis* Cole
OL-8	*Lepidocyclina parvula* Cole
OL-9	*Aurila kniffeni* (Howe and Law)
OL-10	*Pararotalia mexicana mecatepecensis* Nuttall
	Eocene Series
Late Eocene:	
UE-1	*Bulimina jacksonensis* Cushman
UE-2	*Robulus gutticostatus* (Gumbel) var. *cocoaensis* (Cushman)
UE-3	*Amphistegina pinarensis* Cushman and Bermudez var. *cosdeni* Applin and Jordan
UE-4	*Lepidocyclina ocalana* Cushman
UE-5	*Lepidocyclina ocalana floridana* Cushman
UE-6	*Eponides jacksonensis* (Cushman and Applin)
UE-7	*Gyroidina crystalriverensis* Puri
UE-8	*Globigerina tripartita* Koch
UE-9	*Operculina mariannensis* Vaughn
UE-10	*Cytheretta alexanderi* Howe and Chambers
UE-11	*Clithocytheridea caldwellensis* (Howe and Chambers)
UE-12	*Clithocytheridea garretti* (Howe and Chambers)
UE-13	*Jugosocythereis bicarinata* (Swain)
UE-14	*Haplocytheridea montgomeryensis* (Howe and Chambers)
UE-15	*Asterocyclina* sp.

scale. Coastal Plain sediments were laid down on an eroded surface developed on igneous intrusive rocks, low-grade metamorphic rocks, mildly metamorphosed Paleozoic sedimentary rocks, and graben-fill sedimentary deposits of Triassic to Early Jurassic age (Barnett, 1975; Neathery and Thomas, 1975; Chowns and Williams, 1983). Because rocks older than Early Jurassic lie at great depths, their relations and configurations are not as well known as those of the shallower Coastal Plain rocks.

The poorly consolidated Coastal Plain sediments are easily eroded. The carbonate rocks are dissolved by downward-percolating water, the result being the formation of karst topography where such rocks are at or near the surface. Accordingly, the topography developed in much of the study area is characterized by (1) extensive, slightly dissected plains, (2) low, rolling hills, and (3)widely spaced drainage. Local to subregional sinkhole topography is present where limestone rocks lie at or near land surface. A series of

Middle Eocene:	
ME-1	*Asterigerina texana* (Stadnichenco)
ME-2	*Dictyoconus* sp.[1]
ME-3	*Spirolina coreyensis* (Cole)
ME-4	*Lituonella floridana* (Cole)
ME-5	*Discorbis inornatus* Cole
ME-6	*Valvulina cushmani* Applin and Jordan
ME-7	*Valvulina martii* Cushman and Bermudez
ME-8	*Discorinopsis gunteri*[1] Cole
ME-9	*Fabularia vaughani* Cole and Ponton
ME-10	*Textularia coreyensis* Cole
ME-11	*Gunteria floridana* Cushman and Ponton
ME-12	*Pseudorbitolina cubensis* Cushman and Bermudez
ME-13	*Globorotalia bullbrooki* Bolli
ME-14	*Amphistegina lopeztrigoni* Palmer
ME-15	*Ceratobulimina stellata* Bandy
ME-16	*Globorotalia spinulosa* Cushman[2]
ME-17	*Clypeina infundibuliformia* Morellet and Morellet (alga)
ME-18	*Leguminocythereis petersoni* Swain
ME-19	*Lepidocyclina antillea* Cushman (=*L. gardnerae* Cole)
Early Eocene:	
LE-1	*Miscellanea nassauensis* Applin and Jordan
LE-2	*Helicostegina gyralis* Barker and Grimsdale[3]
LE-3	*Lockhartia* sp.
LE-4	*Globorotalia formosa gracilis* Bolli
LE-5	*Globorotalia subbotinae* Morozova
LE-6	*Globorotalia wilcoxensis* (Cushman and Ponton)
LE-7	*Pararotalia trochoidiformis* (Lamarck)
LE-8	*Brachycythere jessupensis* Howe and Garrett
LE-9	*Haplocytheridea sabinensis* (Howe and Garrett)
LE-10	*Pseudophragmina (Proporocyclina) cedarkeyensis* Cole
Paleocene Series	
P-1	*Globorotalia pseudomenardii* Bolli
P-2	*Borelis floridanus* Cole
P-3	*Borelis gunteri* Cole
P-4	*Valvulammina nassauensis* Applin and Jordan
P-5	*Globorotalia angulata* (White)
P-6	*Globorotalia pseudobulloides* (Plummer)
P-7	*Cythereis reticulodacyi* Swain
P-8	*Krithe perattica* Alexander
P-9	*Trachylebris prestwichiana* (Jones and Sherborn)
P-10	*Globorotalia velascoensis* (Cushman)

[1] Locally these species may also occur in rocks of Oligocene age.
[2] Occurs locally in rocks of late early Eocene age.
[3] Occurs locally in the lower part of the middle Eocene.

sandy marine terraces of Pleistocene age has been developed in much of the area. Stringfield (1966) has discussed the physiography of the study area in detail.

Coastal Plain sediments in the project area can be separated into two general facies: (1) predominantly clastic rocks containing minor amounts of limestone that extend southward and eastward toward the Atlantic Ocean and the Gulf of Mexico from the Fall Line that marks the inland limit of the Coastal Plain and (2) a thick, continuous sequence of shallow-water platform carbonate rocks that underlie southeastern Georgia and all of the Florida peninsula. In north-central Florida and in southeastern Georgia, where these clastic and carbonate rocks generally interfinger with one another, facies changes are both rapid and complex. In general, the limestone facies of successively younger units extends progressively farther and farther updip and encroaches to the northwest upon the clastic rocks in an onlap relation, at least until the end of Oligocene time. Miocene and younger rocks comprise a clastic facies that, except where it has been removed by erosion, covers the older carbonate rocks everywhere. The various stratigraphic units within both the clastic- and the carbonate-rock areas are separated by unconformities that represent breaks in sedimentation. As in most regional studies, however, these unconformities are not synchronous surfaces that extend throughout the project area.

Cretaceous rocks generally crop out in a band adjacent to the crystalline rocks and folded strata of the Piedmont and Appalachian provinces. In northeastern Georgia, Eocene and Miocene sediments cover rocks of Cretaceous age in an overlap relation. Figure 2 is a generalized geologic map showing the distribution of rocks of various ages in and adjacent to the project area. Rocks of Tertiary age, whose carbonate facies comprise most of the Floridan aquifer system, crop out in a discontinuous band seaward of the Cretaceous sediments and are also exposed in an area in western peninsular Florida. Still farther seaward, a band of predominantly clastic rocks of Miocene age crops out to form the upper confining unit of the Floridan aquifer system. Miocene rocks generally separate the Floridan from Pliocene and Quaternary strata that are mostly sands and comprise a surficial (unconfined) aquifer.

RELATION OF STRATIGRAPHIC AND HYDROGEOLOGIC UNITS

In the multistate area covered by this study, many formation and aquifer names have been applied to parts of the carbonate rocks that together are called the Floridan aquifer system in this report. To avoid confusion and cumbersome terminology, the stratigraphic units mapped herein are time-rock units that may include all or parts of several formations. The relation between formation (rock-stratigraphic) terminology and the time-rock (chronostratigraphic) units mapped is shown on a correlation chart (pl. 2). Also delineated on this chart are the formations or parts of formations that are included in the Floridan aquifer system.

Just as it is necessary in a regional study to group several geologic formations into regionally extensive units, so must the rocks be grouped according to their general water-bearing properties. Accordingly, the Floridan aquifer system as mapped in this report represents a vertically continuous sequence of carbonate rocks that are in general highly permeable. The aquifer system is everywhere underlain by low-permeability materials that may be clastic, carbonate, or evaporite rocks. Except where the aquifer system is unconfined, it is overlain by clastic or impure carbonate rocks of low permeability.

Within the sequence of generally high permeability carbonate rocks are confining units of local to subregional extent. Over much of the study area, the subregional-scale confining units separate the Floridan aquifer system into upper and lower high-permeability zones, called the Upper and Lower Floridan aquifers, respectively. A discussion of the aquifer-confining unit terminology used in this report and companion chapters of Professional Paper 1403 is given by Johnston and Bush (1985). Locally, there may be several thin to moderately thick low-permeability units of limited areal extent within either of the high-permeability zones (for example, well FLA-FRA-7, cross section E-E', pl. 21; well GA-CHA-8, fig. 12). The amount of low-permeability rock within the aquifer system varies greatly. In the north-central part of the Florida peninsula, much of the aquifer system is highly permeable; in places in southern Florida, as much as 40 percent of the system is low-permeability rock. The confining units may consist of micritic limestone, fine-grained dolomite, or limestone and dolomite that once were permeable but whose pores are now filled with evaporite minerals; in places, the confining units may represent zones of recrystallization.

GEOLOGIC STRUCTURE

The general configuration of Coastal Plain sediments in the study area is a tilted wedge that slopes and thickens seaward from the Fall Line. Superimposed on this prism-shaped mass of sediment are gentle warps of subregional extent. Local to subregional fault systems cut all or parts of the sediment wedge in places. Some of the more prominent features

that interrupt the gentle seaward slope of these Coastal Plain sediments and that have been recognized for many years are shown in figure 3. The major features shown in this figure affected Coastal Plain sediment distribution and configuration over long periods of geologic time. The large positive and negative folds in and contiguous to the Florida peninsula fall into this category. Other features, particularly some of the smaller faults shown in figure 3, were active structures for only a relatively short time, and many of them accordingly had little effect (other than local) on sedimentation.

The dominant influence on sedimentation in the study area has been the Peninsular arch, a northwest-trending feature that was continuously positive from early Mesozoic (Jurassic) until Late Cretaceous time and was intermittently positive during Cenozoic time. Southwest of and parallel to the Peninsular arch is the Ocala "uplift," which affects only rocks of middle Eocene age and younger. Although these two features are often confused in the literature, they are, in fact, distinct entities whose origins are not the same (Winston, 1976). The shape of the Peninsular arch and its effect on sedimentation in north-central Florida resemble those of an upwarp produced by compressional tectonics. Because the Ocala "uplift," does not warp or otherwise affect sediments older than middle Eocene, it is not a true uplift. This feature was produced by sedimentational processes—either an anomalous buildup of middle Eocene carbonate sediments (Win-

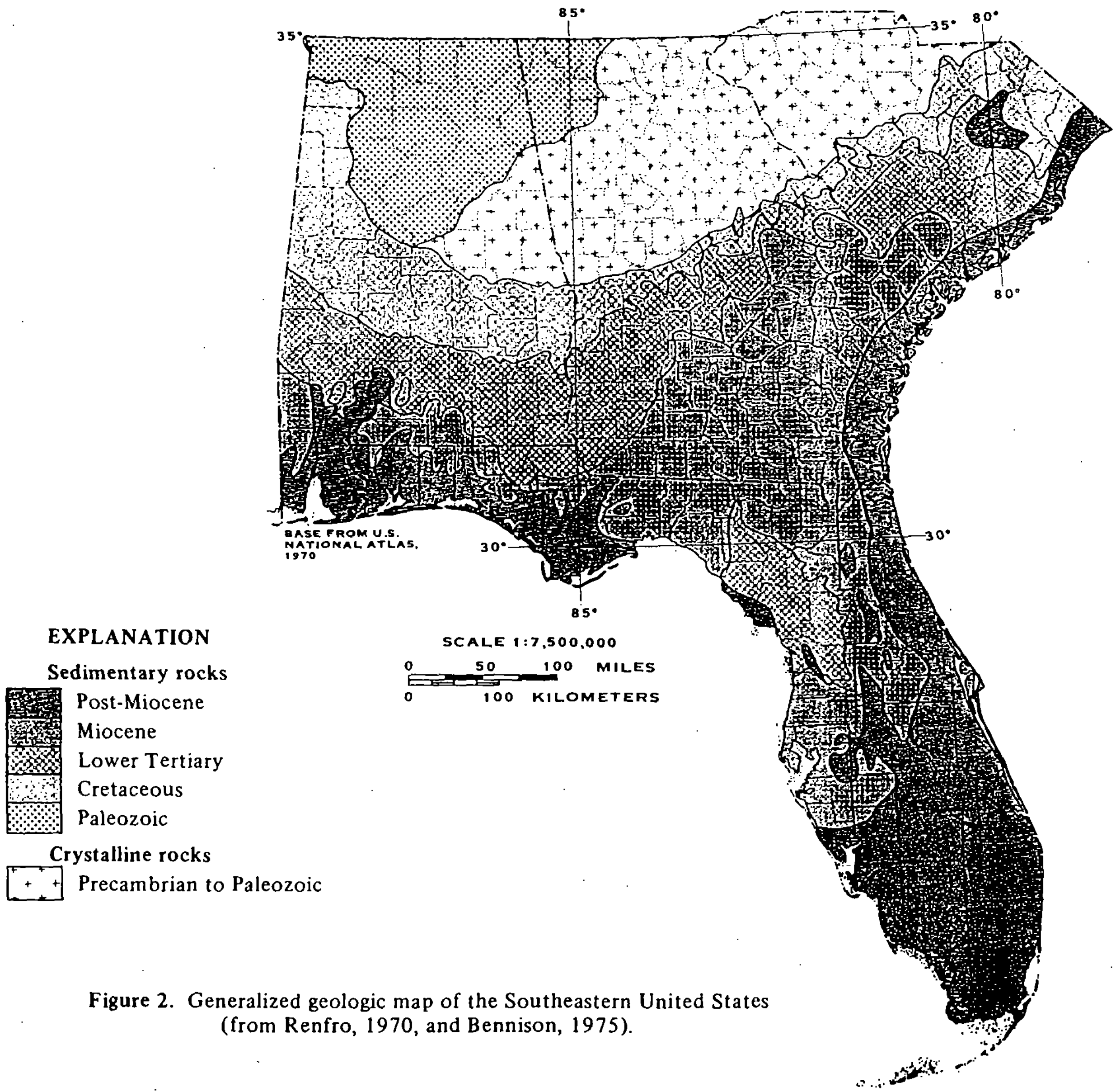
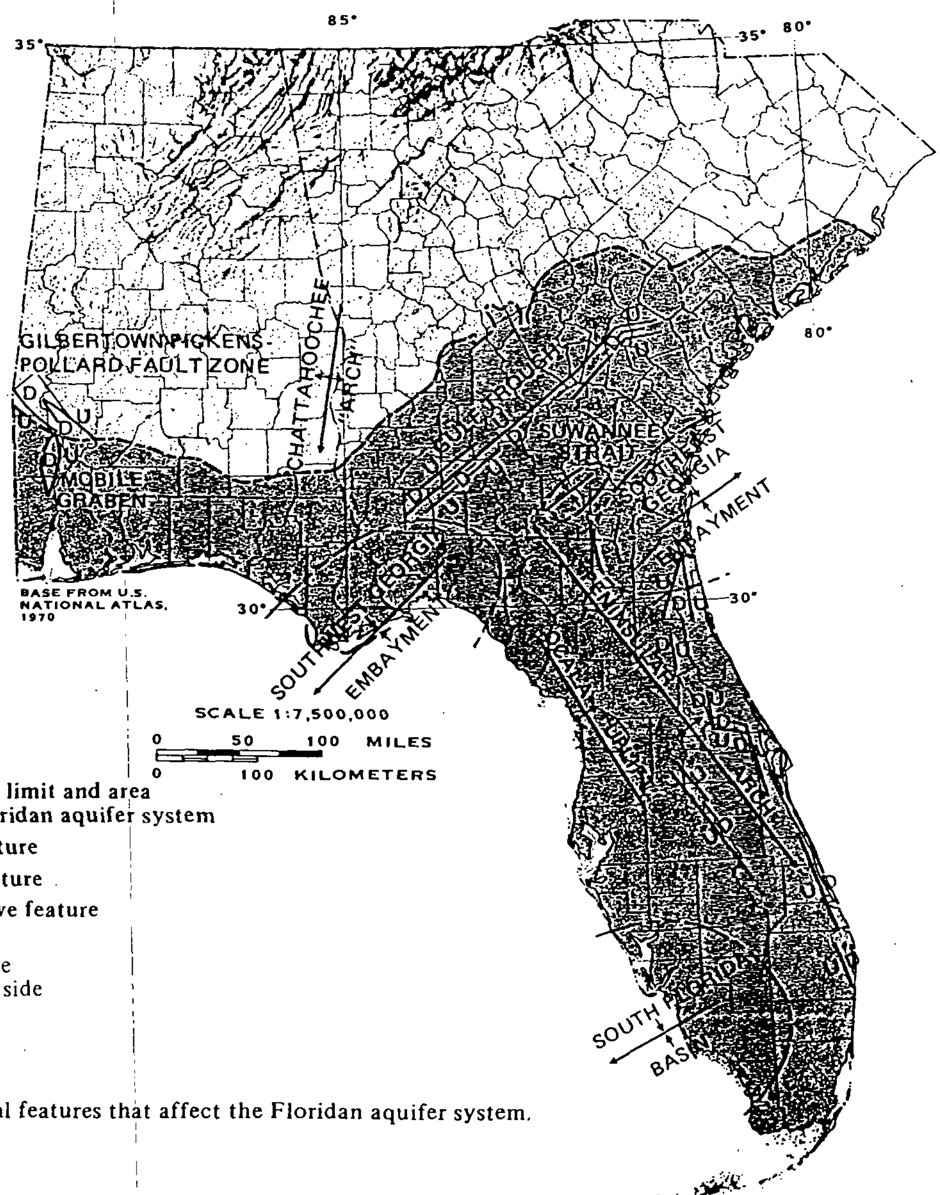


Figure 2. Generalized geologic map of the Southeastern United States (from Renfro, 1970, and Bennison, 1975).

ston, 1976) or, more likely, differential compaction of middle Eocene carbonate material shortly after deposition. Drilling on the "crest" of the Ocala "uplift" shows that the feature is not of deltaic or reefal origin.

A subtle feature that appears at first to be a structural high is located in southeastern Alabama and southwestern Georgia, roughly parallel to the Chattahoochee River. This apparent high has been called the Chattahoochee arch or anticline (Murray, 1961). At places along this feature, outcropping older rocks (Eocene) are surrounded by younger rocks (Oligocene), a situation that would seem to indicate an anticline. However, Patterson and Herrick (1971) thought that such an interpretation was incorrect. A positive structure did, in fact, exist in the general area of the "Chattahoochee arch" during Jurassic time (Miller, 1982g) but there is no evidence that it persisted beyond the end of the Jurassic. No positive feature is shown in the Chattahoochee River area on maps of the tops or thicknesses of the different time-stratigraphic and hydrologic units differentiated in this report. The "Chattahoochee arch" is considered to be an erosional feature rather than a structural one.

The Peninsular arch is flanked on three sides by negative features that have been depocenters since at least Early Cretaceous time (fig. 3). To the south, a thick sequence of platform carbonates was deposited in the South Florida basin. To the northeast, in the



EXPLANATION

Approximate updip limit and area underlain by Floridan aquifer system

Axis of positive feature

Axis of negative feature

Boundary of negative feature

U/D Fault

U Upthrown side

D Downthrown side

Figure 3. Structural features that affect the Floridan aquifer system.

Southeast Georgia or Savannah embayment, deposition of Lower Cretaceous clastic sediments was followed by deposition of carbonate rocks in the Late Cretaceous and early Cenozoic, which in turn was followed by deposition of Upper Cenozoic clastic rocks. The Southeast Georgia embayment represents a shallow east- to northeast-plunging syncline that subsided at a moderate rate. To the northwest of the Peninsular arch is the Apalachicola or Southwest Georgia embayment, a southwest-plunging syncline where a thick section of predominantly clastic rocks has been deposited, almost continuously, since Late Jurassic time. Rarely, in the Cenozoic, carbonate deposition spilled over westward into the Southwest Georgia embayment from the Florida carbonate platform located to the east. Farther westward, in extreme western panhandle Florida and in southern Alabama, time-stratigraphic units thicken abruptly and their tops slope steeply gulfward, reflections of the influence of the rapidly subsiding Gulf Coast geosyncline. The top and base of the Floridan aquifer system also reflect this steep gulfward slope. The limestone that comprises the Floridan, however, thins gulfward as it is replaced by fine-grained clastic rocks. This facies change continues until the limestone is absent altogether in a well about 60 mi offshore from Mobile Bay, Ala.

A negative feature in southeastern Georgia, just north of the Peninsular arch, has been called the Suwannee strait (Dall and Harris, 1892), channel (Chen, 1965), or saddle (Applin and Applin, 1967). This basin was first called a strait because it was thought to represent a channellike feature, perhaps similar to the modern Straits of Florida, that developed on the sea floor and received little sedimentation because it was swept clean by bottom currents. The feature was also thought to represent the boundary between carbonate sediments to the south and clastic sediments to the north. This carbonate-clastic boundary, however, migrates with time in a general northwest direction and is not always confined to the Suwannee strait area. Well data show a closed depression on the top of Paleocene rocks in southeastern Georgia that may be an arm of the Southeast Georgia embayment but is separated from the main body of the embayment by a sill-like ridge. The absence of such a depression in the top of rocks of lower Eocene age or younger shows that the Suwannee strait ceased to be an actively subsiding basin during the early Eocene. Accordingly, this feature had little effect on the Floridan aquifer system, although the Floridan is slightly thicker within it. Because the Suwannee strait area is a closed basin within which several stratigraphic units are anomalously thin, the exact origin of the basin is not clear. Perhaps "starved-basin" conditions during the time of deposition produced units that are thinner than what would be expected.

Several faults and fault systems are shown in figure 3. In western Alabama, north-trending arcuate faults bound the Mobile Graben, a negative feature that shows much vertical displacement (Murray, 1961). The faults to the north of the Mobile Graben are part of the Gilbertown-Pickens-Pollard fault zone, which is characterized by a series of both isolated and connected grabens. The northeast-trending series of small faults in central Georgia (fig. 3) are the boundary faults for a series of small grabens that, taken together, have been called the Gulf Trough, first described by Herrick and Vorhis (1963) and later by Gelbaum (1978) and Gelbaum and Howell (1982). Within the grabens bounded by the faults shown in figure 3, low-permeability clastic rocks have been downdropped opposite the limestone of the Floridan aquifer system and thus retard the flow of ground water within the system. Several faults shown along Florida's eastern coast (fig. 3) are of limited extent and generally show little vertical displacement. These small faults do not appear to have any effect on ground-water flow in the Floridan aquifer system.

STRATIGRAPHY

GENERAL

Because relief in the study area is generally low, outcrops of Coastal Plain strata are sparse. Accordingly, the stratigraphic units delineated herein, like the major permeability variations mapped, are based primarily on data from wells. Standard techniques of subsurface stratigraphic analysis were used to distinguish and map the separate stratigraphic units. Complex facies variations exist within all rock units throughout the study area; hence, chronostratigraphic units were mapped rather than rock-stratigraphic units. The upper and lower boundaries of the chronostratigraphic units have been made to coincide with rock-stratigraphic (lithologic) boundaries within each well used as a control point. The same rock type may not necessarily mark the boundary of the same chronostratigraphic unit from well to well, however, especially in places where facies change rapidly. Each chronostratigraphic unit may therefore encompass several different rock types. The formations or parts of formations included in the several chronostratigraphic units are shown on plate 2. The chronostratigraphic units are discussed below, from oldest to youngest. Only those units that are part of the Floridan aquifer system or its confining units are mapped

and described. Thus, most of the units are not mapped past the updip limit of the aquifer system, even though some are known to continue for a considerable distance updip from the system.

The chronostratigraphic units delineated and mapped represent sequences of rocks judged to have been deposited over a given interval of geologic time. Because exact dating of the rocks is not available, the relative ages of the different units mapped are determined by the fauna (chiefly microfauna) that the rocks contain. The identity of the separate chronostratigraphic units, however, does not depend upon the presence of a certain fauna within them. Many of the "formations" in the subsurface in the area, particularly those in Florida, were originally defined as "a distinct microfaunal unit," or as the sequence of rocks extending between the highest stratographic occurrences of two concurrent species that were judged to be time diagnostic (see, for example, Applin and Applin, 1944). Under the rules of the present North American Stratigraphic Code, a unit defined on the basis of its faunal content is neither a time-stratigraphic unit nor a rock-stratigraphic unit; rather, it is a biostratigraphic unit (North American Commission on Stratigraphic Nomenclature, 1983). Many of the species described in the literature as being diagnostic of a particular "formation" are, in fact, good time markers in the study area and are recognized as such in this report (table 1). The fauna used in this study, however, serve only to support the assignment of strata to a particular chronostratigraphic unit and are nowhere the sole criterion by which any unit mapped herein is recognized. After a given unit's relative age is established, the top and bottom of the unit are adjusted at each well control point to match lithologic changes as shown in core or by a change in electric log pattern.

The external geometry of the different chronostratigraphic units is shown by a series of maps (pls. 3-14) that portray the configuration of the top of a particular unit or its thickness. Variations in the lithology of the units are shown on a series of cross sections (pls. 15-24) that were chosen to also demonstrate the permeability variations within the Floridan aquifer system and its confining units.

CRETACEOUS SYSTEM: GULFIAN SERIES

Rocks of the Gulfian Series of Late Cretaceous age underlie the entire study area and include, in ascending order, units equivalent to the Woodbinian, Eagle Fordian, Austinian, Tayloran, and Navarroan provincial stages of the gulf coast Upper Cretaceous. In the area covered by this study, the Gulfian Series is found only in the subsurface. North of the study area, rocks of the Gulfian Series comprise practically all of the band of outcropping Cretaceous strata found at or near the contact of Coastal Plain sediments and older crystalline rocks (fig. 2). Applin and Applin (1967) mapped and described the Gulfian Series over much of the study area. This report deals only with the rocks that are part of the Tayloran and Navarroan stages because they are the oldest geologic units that comprise either a part of the Floridan aquifer system or its lower confining unit.

ROCKS OF TAYLOR AGE

In the shallow subsurface and in outcrop, Tayloran rocks include parts of the Mooreville and Demopolis Chalks and the Cusseta Sand Member of the Ripley Formation in Alabama, parts of the Cusseta Sand Member of the Ripley Formation and the Blufftown Formation in Georgia; and the upper part of the Black Creek Formation and the lower part of the Peedee Formation of South Carolina (Hazel and others, 1977). Rocks of Taylor age, however, are unnamed in most of the subsurface of the eastern Gulf Coast, including the area covered by this study. Practically all Tayloran strata in the report area consist of low-permeability rocks that range from light-gray, massive, often calcareous clay in southern Alabama, panhandle Florida, and much of central Georgia to chalk or argillaceous chalk in most of peninsular Florida. Thin layers of dolomite are interbedded with the chalk over much of Florida. Beds of fine- to medium-grained glauconitic sand are present in northeastern Georgia and South Carolina, along with carbonaceous material and local shell beds. Clayey beds of Taylor age in northeastern Georgia and South Carolina are usually darker in color and contain less calcareous material than similar beds elsewhere in the study area. The Tayloran chalks of peninsular Florida are part of a thick Upper Cretaceous chalk sequence and can be differentiated only on the basis of their microfauna (Applin and Applin, 1967; Maher, 1971). All Tayloran strata in the study area were deposited in a marine environment. In Florida, southern Alabama, and southwestern Georgia, these rocks represent middle to outer shelf conditions; in northeastern Georgia and South Carolina, they were laid down in marginal marine and inner shelf environments.

Rocks of Taylor age attain a maximum thickness of about 1,300 ft in the study area (Applin and Applin, 1967) and are everywhere underlain by rocks of Austin age. Over much of the area, beds of Navarro age overlie Tayloran rocks. In panhandle Florida, southern Alabama, and southwestern Georgia, however, rocks of Navarro age are thin and discontinuous; here, rocks

of Paleocene age may lie directly on rocks of Taylor age (Applin and Applin, 1967). A map showing the configuration of the top of the Cretaceous (fig. 4) is accordingly a composite map representing the tops of several Cretaceous units. Most of the major geologic structures that affect the stratigraphic and permeability units comprising the Floridan aquifer system are shown on this map (compare figs. 3 and 4). The low areas shown in figure 4 in southeastern Georgia and southwestern peninsular Florida represent the Southeast Georgia embayment and the South Florida basin, respectively. The high area in northern Florida is the Peninsular arch. Also shown in figure 4 is the steep, southwest-trending slope of the northern rim of the Gulf Coast geosyncline, and a series of faults in southwestern Alabama that represent the Mobile Graben and the Gilbertown-Pickens-Pollard fault zone.

Fauna considered characteristic of rocks of Taylor age in the eastern Gulf Coast include the foraminifers *Bolivinoides decoratus* Jones, *Stensionina americana* Cushman and Dorsey, *Marsonnella oxycona* (Reuss), *Dorothia glabrella* Cushman, *Globotuncana ventricosa* White, *G. elevata* (Brotzen), and *G. calcarata* Cushman and the ostracod *Brachycythere sphenoides* (Reuss).

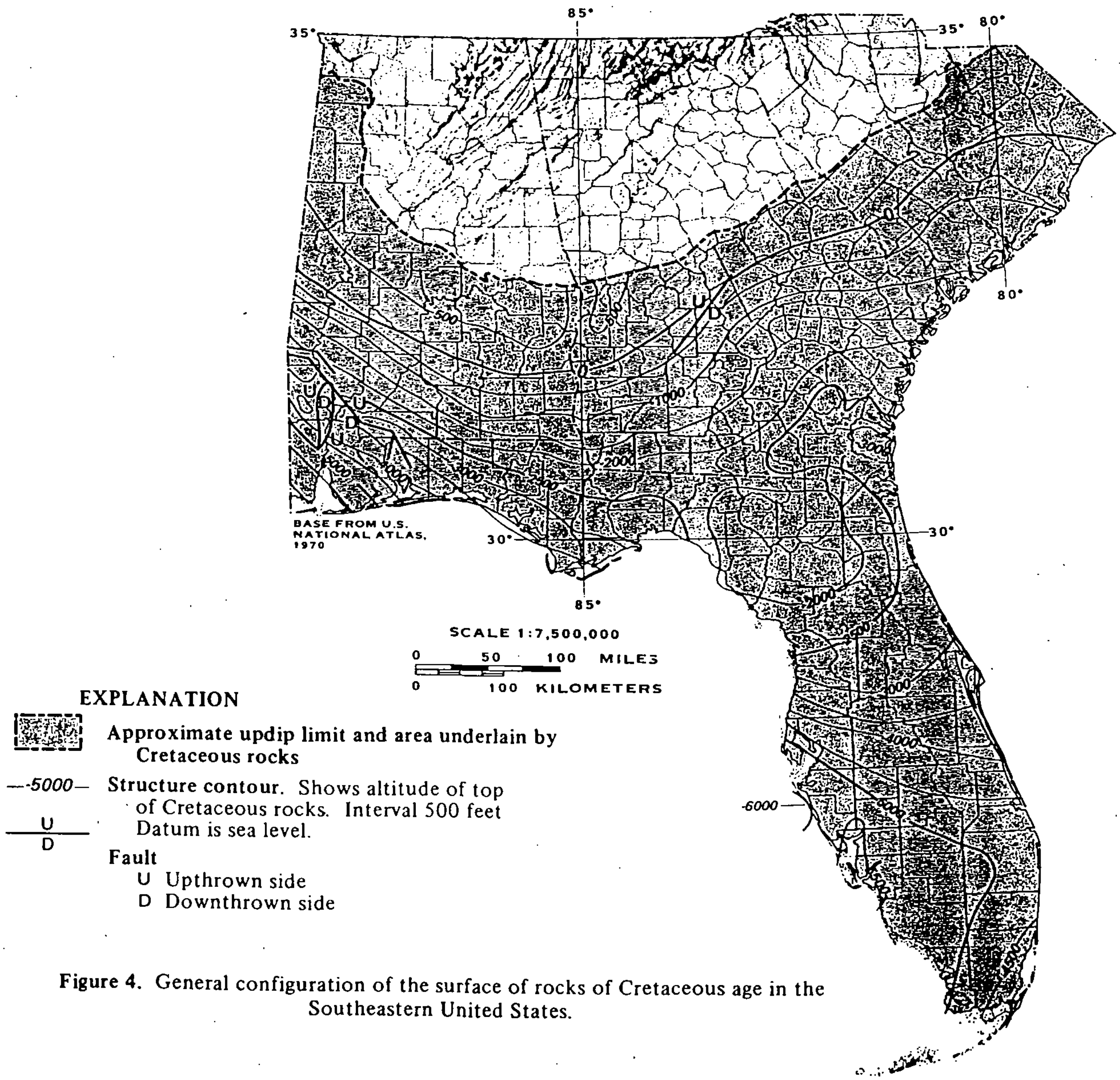


Figure 4. General configuration of the surface of rocks of Cretaceous age in the Southeastern United States.

ROCKS OF NAVARRO AGE

In outcrop and in the shallow subsurface, Navarroan rocks include the Prairie Bluff Chalk, the Ripley Formation (except for the Cussetta Sand Member), and the upper part of the Demopolis Chalk in Alabama; the Ripley Formation (again, excluding the Cusseta Sand Member) and the Providence Sand in Georgia; and the upper part of the Peedee Formation in South Carolina (Hazel and others, 1977). Downdip, rocks of Navarro age are unnamed except for the Lawson Limestone of northern Florida and southeastern Georgia (Applin and Applin, 1944, 1967). As mentioned previously, beds of Navarro age are thin and discontinuous over much of the area, particularly where these strata are clastic. Navarroan rocks in the study area can be grouped into four general facies: (1) calcareous gray shale interbedded with thin, fine-grained sand in southern Alabama and panhandle Florida; (2) light- to dark-gray, glauconitic, locally shelly and calcareous sand, clayey sand, and clay in northeastern Georgia and South Carolina; (3) dominantly tan to white, pelletal, soft, friable, locally gypsiferous dolomitic limestone (Lawson Limestone) that contains the remains of algae and rudistid pelecypods in north-central Florida and southeastern Georgia (the Lawson is locally very porous owing to a decrease in its micrite matrix, and, where it is porous it is included as part of the Floridan aquifer system); (4) white chalk interbedded with light-gray argillaceous micritic limestone in southern peninsular Florida. The transition from clastic to carbonate rocks is abrupt and takes place along a northeast-trending line in southern Georgia, where both clastic and carbonate materials thin drastically. Navarroan rocks thicken to the northwest and southeast of this line, which is located approximately in the area labeled "Suwannee strait" on figure 3, and along its extension to the southwest. Applin and Applin (1967) thought that this area of thin Navarroan sediments represented a flexure that was positive during much of Late Cretaceous time but subsequently became a negative feature.

Although the Lawson Limestone is quite extensive, it is only in and near the Brunswick, Ga., area that the Lawson is sufficiently permeable to be considered part of the Floridan aquifer system. Elsewhere, rocks of Navarro age are of low permeability. The Lawson can be readily recognized because of its distinctive lithology and the rudistid pelecypod fauna that it commonly contains. Micritic limestone and clayey strata of Navarro age, by contrast, can often be distinguished from older rocks only on the basis of the microfauna that they contain. Rocks of Navarro age reach a maximum thickness of about 600 ft in southern peninsular Florida. For the most part, however, they are less than 200 ft thick.

Fauna characteristic of Navarroan rocks include the rudistid pelecypods mentioned earlier and the foraminifers *Vaughanina cubensis* Palmer, *Lepidorbitoides nortoni* (Vaughan), and *Sulcoperculina cosdeni* Applin and Jordan.

Fine-textured Navarroan strata in the study area were deposited in middle to outer shelf environments. The clastic rocks of Navarro age that lie updip from the chalks and micritic limestones were laid down in inner shelf to shoreline environments.

TERTIARY SYSTEM

PALEOCENE SERIES

GENERAL

Rocks of Paleocene age underlie the entire study area and can be grouped into two general facies categories: (1) a carbonate-evaporite facies that consists mostly of interbedded dolomite and anhydrite and (2) a clastic facies that consists primarily of shallow-marine clay and minor amounts of fine sand and impure limestone. The carbonate-evaporite facies underlies all of peninsular Florida and a small part of southeastern Georgia, and the predominantly clastic facies lies to the north and west of the carbonate platform. The demarcation between these two facies is sharp, and they are assumed to interfinger with each other over a narrow transition zone, although no well drilled to date (1983) has shown such interfingering.

The distribution of the clastic and carbonate facies in rocks of Paleocene age is shown on plate 3, which also shows the configuration of the top of the Paleocene and the area where rocks of Paleocene age crop out. In Alabama and extreme western Georgia, the top of the Paleocene is contoured into the outcrop area. From central Georgia northeastward to South Carolina, the updip extent of the Paleocene is based on well control because Paleocene rocks are mostly overlapped there by younger strata. In South Carolina, the Paleocene is known to extend for a considerable distance to the north of the contours shown on plate 3. Paleocene rocks were contoured only to the limit of the well control used to delineate the Floridan aquifer system.

Plate 3 shows that several large-scale structural features affect the shape of the top of Paleocene rocks. In the western third of the study area, the Paleocene top slopes steadily at a rate of about 30 ft/mi toward the axis of the Gulf Coast geosyncline. Farther eastward, a low area of moderate size extending from Franklin County to Leon County, Fla., represents the

Southwest Georgia embayment. In north-central Florida, a northwest-trending high area is the Peninsular arch. The depression contours to the north of this arch represent the Suwannee strait, which is silled to the east by a slight rise in the Paleocene top. East of this sill, the Paleocene top descends into the Southeast Georgia embayment. The depression contours in southern peninsular Florida represent part of the South Florida basin, which was silled to the west by the Charlotte high (Winston, 1971), a local positive feature. The broad negative area that extends northwestward across east-central Georgia and the southeast-plunging positive feature that parallels it to the northeast are both unnamed. The magnitude of these warps on the Paleocene top shows that they are structural rather than erosional in origin.

The maximum measured depth to the top of the Paleocene Series is 4,680 ft below sea level in well ALA-BAL-30 in Baldwin County, Ala. The maximum contoured depth of the top is below 5,000 ft in the same general area. In southern Florida, the Paleocene top reaches a maximum measured depth of about 3,660 ft in eastern Glades County (well FLA-GL-1).

A primary objective of this hydrogeologic investigation was to delineate and map permeability variations within the Floridan aquifer system. As a later section of this report will discuss, evaporite-bearing rocks of Paleocene age comprise the base of the system over much of the Floridan's area of occurrence. Elsewhere, younger rocks make up the base of the system. Neither permeability nor stratigraphy was mapped below the middle part of the Paleocene (except very locally, in the Brunswick, Ga., area, where all of the Paleocene and part of the Upper Cretaceous are included in the aquifer system). No isopach map of Paleocene rocks was constructed because the base of the Paleocene was not mapped. The thickness of clastic Paleocene rocks, however, is known to exceed 1,400 ft in Mobile County, Ala. (well ALA-MOB-16). The Paleocene carbonate-evaporite sequence is known to be slightly more than 2,200 ft thick in southern Florida (well FLA-LEE-3, Lee County).

Paleocene rocks in the study area can be assigned to several formations (pl. 2). Of these units, only the upper part of the Cedar Keys Formation of Florida and southeastern Georgia is part of the Floridan aquifer system. Anhydrite beds in the Cedar Keys, which are areally extensive and usually occur near the base of the upper third of the unit, form the base of the aquifer system over most of peninsular Florida. Updip from the Cedar Keys, clayey Paleocene strata that are equivalent to part of the Clayton Formation locally comprise the base of the system. In eastern Alabama and western Georgia, ground water is obtained from limestone of the Clayton Formation, but this limestone is nowhere connected to the main body of Tertiary limestone mapped as the Floridan aquifer system.

At the time of this writing (1984), the boundary between Paleocene and Eocene strata in the eastern Gulf Coast is being revised. The work of Berggren (1965), as well as more recent work (Oliver and Mancini, 1980; Gibson, 1980, 1982a), has shown that rocks in Alabama that were long thought to be part of the early Eocene are actually of late Paleocene age. Some formations (such as the Tuscahoma) that contain Paleocene index fossils in their lower parts only are mapped herein as part of the Paleocene. Most of the recent stratigraphic revisions of the Paleocene-Eocene boundary have been in the outcrop area of southern Alabama; most of the mapping done during this study, however, was based on deep subsurface data, and the question of the Paleocene-Eocene boundary therefore becomes a problem only as subsurface correlations are projected toward outcrop. Because the boundary is still in a state of revision, it is important to briefly summarize the history of the problem and set forth the rationale used in this report for assigning a Paleocene age to certain rock units.

Beds in the eastern Gulf Coast that are now known to be of Paleocene age were thought to be part of the Eocene Series before the discovery of a Paleocene fossil mammal in a well in Louisiana (Simpson, 1932). Subsequently, these beds were grouped into the provincial Midwayan Stage, a time-stratigraphic unit comprised of formations that could be dated mostly as Paleocene primarily on the basis of their molluscan fauna. Over the years, the term Midway became synonomous with the term Paleocene. In the eastern Gulf Coastal Plain, the Midwayan Stage included the Clayton, Porters Creek, and Naheola Formations (pl. 2), although the Naheola was recognized to be lithologically similar to beds of the overlying Wilcox Group (Toulmin, 1977). The term "Wilcox Group" itself has been controversial (Murray, 1955, 1961), for "Wilcox" has been used in a time-stratigraphic sense (synonomously with Sabinian Stage to designate early Eocene rocks) as well as in a rock-stratigraphic sense (Wilcox Group). In the eastern Gulf Coast, the Nanafalia, Tuscahoma, and Hatchetigbee Formations (pl. 2) traditionally have been considered to comprise the Wilcox Group and to be of early Eocene age.

More recently, the Paleocene and Eocene section of the Gulf Coast has been correlated with the European section by using planktic microfauna (chiefly Foraminifera and calcareous nannoplankton), which are considered to be worldwide stratigraphic markers (Berggren, 1965, 1971, 1977; Oliver and Mancini, 1980; Bybell, 1980; Gibson and others, 1982). The Nanafalia Formation of Alabama, formerly thought to be of early Eocene age, has been shown to consistently contain

the planktic foraminifer *Globorotalia pseudomenardii* Bolli, a worldwide Paleocene form. The generic placement of certain planktic species has recently been revised by some authors. For example, *Globorotalia pseudomenardii* is presently considered to belong to the genus *Planorotalites*; *G. subbotinae* and *G. velascoensis* are thought to belong to the genus *Morozovella*. These revisions, however, are not accepted by all micropaleontologists. The taxonomy used for planktic foraminifers in this report and the range of the different species follow Stainforth and others (1975). *Globorotalia pssudomenardii* has been reported (Oliver and Mancini, 1980) from marl beds in the lower part of the Tuscahoma Formation. Higher up in the Tuscahoma, other marl beds contain *G. velascoensis* (Cushman), a form usually shown on foraminiferal zonation charts as ranging into the latest Paleocene. The base of Eocene strata is considered by some authors to be the first occurrence of *G. subbotinae* Morozova (formerly called *G. rex* Martin). However, Oliver and Mancini (1980) recorded *G. subbotinae*, along with *G. velascoensis*, from the same beds in the upper part of the Tuscahoma. Stainforth and others (1975) showed that the range of *G. velascoensis* overlaps the entire range of *G. pseudomenardii* below, and slightly overlaps the range of *G. subbotinae* above.

In the subsurface strata examined during this study, *G. velascoensis* was found to occur commonly in the same beds with *G. pseudomenardii*; accordingly, beds that contain either of these species are considered to be of definite Paleocene age. Beds in the deep subsurface that contain *G. subbotinae* are herein considered to be of early Eocene age. This zonation becomes a problem only in the outcropping Tuscahoma Formation, which, as an earlier discussion pointed out, contains *G. pseudomenardii* in its lower part and *G. subbotinae* in its upper part. Calcareous nannoplankton from marl beds in the Tuscahoma show that these beds are of Paleocene age (Gibson and others, 1982), and sporomorphs from the uppermost Tuscahoma indicate that the entire formation is probably late Paleocene (Frederiksen and others, 1982).

Downdip, all of the Paleocene and lower Eocene formations that are lithologically different in the outcrop area of Alabama grade by facies change into thick marine clay sequences separated by thin sands. The lithology and electric log patterns of these clays are uniform and the strata can be differentiated only on the basis of the microfauna that they contain. Accordingly, the Paleocene in this study was mapped in southern Alabama and western panhandle Florida on the basis of the highest occurrence of *G. velascoensis*. Rocks containing *G. subbotinae* were mapped as part of the early Eocene. As plate 2 shows, rocks of the Tuscahoma Formation or its equivalents are judged to represent the top of the Paleocene. The Hatchetigbee Formation and its equivalents are considered to represent the base of the early Eocene. Plate 2 also shows that neither the units mapped for this study nor the Paleocene-Eocene boundary as determined by Berggren (1971) and Oliver and Mancini (1980) coincides with the traditional concept of the Midwayan and Sabinian provincial stages.

Cedar Keys Formation

Cole (1944c, p. 28) used the name Cedar Keys Formation for "cream to tan colored, hard limestones which contain *Borelis gunteri* Cole and *Borelis floridanus* Cole in their upper portion." Cole thought that the Cedar Keys was an early Eocene unit and equivalent to the "Midway Formation," which at the time was also considered to be early Eocene. Both the Cedar Keys and the "Midway" are now considered to be Paleocene in age. Cole did not specify a type well section for the Cedar Keys. Applin and Applin (1944) called these rocks the "Cedar Keys Limestone" rather than "Formation," but they, like Cole, neglected to specify a type well. Winston (1976) subsequently designated a well in Levy County, Fla. (Coastal Petroleum Company's #1 Ragland, well FLA-LV-4) as the cotype well for the Cedar Keys and redefined the unit on the basis of lithologic criteria rather than paleontologic criteria. Samples examined by this author confirm the findings of Applin and Applin (1944), Chen (1965), and Winston (1976), all of whom observed that the Cedar Keys is practically everywhere either partially or completely dolomitized and that the unit in most places carries intergranular gypsum that fills much of the pore space in the dolomite. Accordingly, the unit should more properly be designated the "Cedar Keys Formation," the terminology used in this report. The upper part of the Cedar Keys usually consists of gray to cream, coarsely crystalline dolomite that is moderately to highly porous. The species of *Borelis* that characterize much of the Cedar Keys section are not present in this uppermost dolomite, because the dolomitization process obliterated any fauna enclosed in the original limestone.

Approximately the lower two-thirds of the Cedar Keys consists of tan to gray, finely crystalline to microcrystalline dolomite interbedded with white to clear anhydrite that commonly shows an interlithic or "chicken wire" texture—that is, thin, veinlike, contorted partings of dolomite separate large nodular masses of anhydrite. This texture, plus the extensive amounts of anhydrite present in the Cedar Keys, shows that the unit was deposited in a tidal flat type of environment, possibly analagous to but more areally extensive than,

a modern sabkha environment. Locally, dolomite strata that are interbedded with the anhydrite contain abundant *Borelis spp.* and the foraminifer *Valvulammina nassauensis* Applin and Jordan, an indication that open marine conditions were reestablished periodically in the tidal flat areas.

The evaporite-dolomite sequence is characteristic of the Cedar Keys of the Florida peninsula (see pl. 3). A sharp demarcation exists between this facies and the clastic Paleocene beds that are part of the Clayton Formation in southern Georgia and its equivalents in panhandle Florida. The Cedar Keys may either interfinger with or grade into these clastic strata. Well data show that the clastic rocks become calcareous near the point where the clastic-carbonate facies change takes place. No well data available to this author show the Cedar Keys in contact with the clastic Paleocene beds, however. The faunal transition between the Cedar Keys and the clastic Paleocene is equally sharp. The *Borelis* fauna characteristic of the Cedar Keys has not been found as of this writing in any well that contains a planktic foraminiferal fauna of definite Paleocene age. Because of this limitation, no definitive age can be assigned to the Cedar Keys, and the unit is placed in the Paleocene in this study solely on the basis of its stratigraphic position. The thin beds of limestone that occur locally at the top of the clastic Paleocene section in the Florida panhandle do not resemble the Cedar Keys in any way.

The thick anhydrite beds of the Cedar Keys, where they are present, form the lower confining unit of the Floridan aquifer system. Locally, in the Brunswick, Ga., area, well data show that the Cedar Keys is permeable throughout (rather than only in the uppermost dolomite beds), and the entire formation is considered to be part of the Floridan aquifer system there.

Clayton Formation and equivalent rocks

The Clayton Formation, at its type area in eastern Alabama, consists mostly of coarse-grained sand and minor amounts of sandy, hard to semi-indurated, mollusk-rich limestone. Downdip for a short distance and eastward into extreme western Georgia, the amount of limestone in the Clayton increases. Still farther downdip, the limestone grades by facies change into a massive calcareous marine clay section that contains a few thin beds of sand. The Clayton thins westward and grades gradually into the sandy, silty Pine Barren Member below and the soft, marly McBryde Limestone Member above (pl. 2). In central and western Alabama, the upper part of the Clayton grades into the massive, dark-colored clay of the Porters Creek Formation (Toulmin, 1977). The Porters Creek is for the most part nonmarine to very shallow marine and is not the same as the marine clay that replaces the Clayton downdip. Scattered well data in central Alabama show that the Porters Creek, like the Clayton, grades laterally downdip into this massive marine clay, but a section of thick-bedded, marine, slightly glauconitic sand and gray to brown subfissile clay intervenes between the two formations. Locally, the uppermost beds of the Porters Creek consist of the thin, abundantly fossiliferous Matthews Landing Marl Member.

Most of the Paleocene strata in Georgia have been placed in the Clayton Formation by Herrick and Vorhis (1963). For the most part, the Clayton in Georgia consists of fine- to medium-grained glauconitic sand and clayey sand and smaller amounts of medium- to dark-gray clay. The top of the Clayton in Georgia is commonly marked by a dark-gray, sandy, glauconitic, hard limestone that usually contains casts and molds of pelecypods and gastropods. This limestone is thickest in western Georgia, where it constitutes an important local source of ground water. In eastern Georgia, near the Savannah River, the amount of dark-colored clay in the Clayton increases and grades laterally into the Black Mingo Formation of South Carolina, which consists mostly of dark-colored, carbonaceous clay and thin beds of fine- to medium-grained sand.

In southeastern Georgia, clastic beds of the Clayton merge along a fairly sharp line (pl. 3) with light-colored dolomite of the Cedar Keys Formation. Locally, in updip areas of the central Georgia Coastal Plain, the Clayton grades into dark-colored clay that has been called the Porters Creek Formation, which in turn grades into sands that may be part of the Huber Formation (Huddlestun, 1981).

Undifferentiated Paleocene rocks

Paleocene rocks in most of panhandle Florida, much of southern Alabama, and a small area in extreme southwestern Georgia consist of massive, gray to greenish-gray, subfissile, calcareous, occasionally sandy and slightly glauconitic marine clay. Eastward, this clay grades into argillaceous limestone, which in turn grades into dolomite and dolomitic limestone of the Cedar Keys Formation. Northward, the clay grades into the sand, clay, and limestone sequence of the Clayton Formation. The massive clay is at present unnamed. Applin and Applin (1944) referred to this unit informally as "the clastic lithofacies of the Paleocene" or as the "Tamesii faunal unit" because these clay beds contain a foraminiferal fauna in their lower part that is similar to the fauna of the lower Paleocene Tamesii (Velasco) Formation of Mexico.

Applin (1964) thought the "Tamesii fauna" represented a span of time roughly equivalent to that during which the Clayton, Porters Creek, and Naheola Formations were deposited. The implication is that the massive clay cannot be differentiated into these three units, as Chen (1965) correctly stated. Chen chose to call the massive clay unit the "Midway Formation." The author prefers the term "undifferentiated Paleocene rocks" because it avoids the implication that the term Midway is synonymous with rocks of Paleocene age.

Microfossils diagnostic of undifferentiated Paleocene strata in the study area include the planktic Foraminifera *Globorotalia pseudomenardii* Bolli, *G. velascoensis* (Cushman), *G. angulata* (White), and *G. pseudobulloides* (Plummer). In shallower water deposits, the Ostracoda *Cythereis reticulodacyi Swain*, *Krithe perattica* Alexander, and *Trachyleberis prestwichiana* (Jones and Sherborn) are characteristic.

Nanafalia Formation

The outcropping Nanafalia Formation in western Alabama can be divided into (1) the lower Gravel Creek Sand Member, a coarse-grained sand, (2) a middle, highly fossiliferous glauconitic sand unit informally called the "*Ostrea thirsae*" beds, and (3) the upper Grampian Hills Member, which consists of dark greenish-gray clay interbedded with minor amounts of glauconitic sand (pl. 2). The Gravel Creek Sand is poorly preserved as local erosional remnants in eastern Alabama. The diagnostic Nanafalia oyster *Odontogryphea thirsae* Gabb, characteristic of the middle part of the Nanafalia, ranges upward into the basal beds of the Grampian Hills Member. The upper and middle parts of the Nanafalia in eastern Alabama and western Georgia grade laterally updip into the Baker Hill Formation (Gibson, 1982a), a sequence of interbedded micaceous sand and kaolinitic, bauxitic, and carbonaceous clay. Nanafalia sediments rapidly become finer grained and more marine in a gulfward direction. In southernmost Alabama and western panhandle Florida, beds that are the equivalent of the Nanafalia are gray to greenish-gray marine clays that are indistinguishable from the underlying clays belonging to undifferentiated Paleocene rocks. The Nanafalia clays can be separated from these older clays only in wells where beds of either limestone or calcareous sand occur between the two thick clay units. The outcropping Nanafalia is known to thin as it loses coarser clastics in a downdip direction (Toulmin, 1977; Reinhardt and Gibson, 1980), and subsurface data still farther downdip show that the Nanafalia (upper) part of the massive marine clay sequence is thin in comparison with the lower part.

Tuscahoma Formation

The Tuscahoma Formation in outcrop and in the shallow subsurface is chiefly silt and silty clay containing some fine-grained sand beds. Locally, sand is the dominant lithology in outcrop areas. Some sand beds are glauconitic and fossiliferous, and two such beds have been named the Greggs Landing and Bells Landing Marl Members. The Tuscahoma grades downdip into soft, brown to gray, calcareous, slightly glauconitic clay that contains much fine-grained organic material and a few beds of fine-grained glauconitic calcareous sand.

Still farther southward, the Tuscahoma grades into gray to greenish-gray marine clays that are included in the undifferentiated Paleocene rocks. *Globorotalia pseudomenardii* Bolli and *G. velascoensis* (Cushman) characterize the Tuscahoma. *G. subbotinae* Morozova, which is found in the outcropping Tuscahoma, is not considered characteristic of the formation in the subsurface.

Local Paleocene units

There are several Paleocene units of local to subregional extent in and contiguous to the study area. One of these is the Ellenton Formation in South Carolina (pl. 2), a thin unit of clay and marl (Siple, 1967) whose extent is poorly known and which is dated in only a few places. Although the Ellenton is possibly equivalent to basal Paleocene deposits in the Charleston, S.C., area (G. S. Gohn, written commun., 1983) that were called Beaufort(?) Formation by Gohn and others (1977), well control is not sufficient to correlate the two units exactly. Faye and Prowell (1982) assigned an early to middle Paleocene age to cored materials in Burke County, Ga., that they thought belonged to the Ellenton Formation. Another such local unit is the Naheola Formation in Alabama, which consists of the lower Oak Hill Member (a laminated dark-colored silt, clay, and sand sequence that is locally fossiliferous) and the upper Coal Bluff Marl Member (a fossiliferous glauconitic sand). The Naheola is not recognized in the subsurface, but its equivalents are possibly part of the massive, unnamed, downdip marine clay of Paleocene age. A third Paleocene unit of minor importance is the Salt Mountain Limestone, a white, massive, dense, microcrystalline to finely crystalline limestone that crops out locally in western Alabama, where it has been upthrown along the Jackson fault zone (Toulmin, 1940; Wind, 1974). The Salt Mountain is thin and discontinuous in the subsurface and occurs as a series of disconnected lenses that typically lie within the upper third of the thick, undifferentiated Paleocene clay sequence.

Depositional environments

Rocks of Paleocene age were for the most part deposited in marine or marginal marine environments. In updip areas, the basal sands of the Clayton Formation represent a transgressive marine sand. Their western equivalents, the laminated, fossiliferous silt and sand of the Pine Barren Member of the Clayton, represent a shallow, restricted marine environment such as a bay or an estuary. Both the Pine Barren and the basal Clayton sands were succeeded by soft, micritic (McBryde Limestone Member) to shelly, sandy limestone that represents a shallow, open marine environment. A minor regression of the sea followed deposition of this limestone, during which a shallow marine sand (part of the Clayton) was laid down in eastern Alabama and the blocky, massive, nonmarine to very shallow marine Porters Creek Formation was deposited in western Alabama. The Matthews Landing Marl Member of the Porters Creek was deposited in a restricted marine environment during a minor transgression near the end of Porters Creek time. In middip areas, the Clayton Formation and its equivalents are entirely shallow marine. The laminated silty sands of the Tuscahoma Formation were deposited in a restricted marine environment, probably a tidal flat. Periodically, local transgressions of the sea covered the tidal flat and allowed deposition of the Greggs Landing and Bells Landing Marl Members. Farther downdip, the massive marine clay that is the deeper water equivalent of the Clayton, the Nanafalia, and the Tuscahoma was deposited in quiet open-marine water in a midshelf area.

To the south and east of the clastic Paleocene rocks, the Cedar Keys Formation was deposited in a shallow, warm-water, carbonate bank environment. The extensive evaporite deposits of the Cedar Keys represent tidal flat or sabkha-type conditions that existed over wide areas and for a long time on this carbonate bank.

The basal part of the Naheola Formation in western Alabama (Oak Hill Member) represents a fluvial to very shallow marine (tidal flat accompanied by occasional oyster banks) environment. The succeeding Coal Bluff Marl Member of the Naheola was deposited in a restricted marine to very shallow open marine environment. Downdip, the Naheola probably passes by facies change into part of the massive, open marine clay that forms most of the downdip Paleocene. Well control is not available to show such a transition, however.

The Salt Mountain Limestone was deposited in an open marine, quiet, shallow-water environment. The Salt Mountain is thin and discontinuous, possibly as the result of postdepositional erosion. In wells where the Salt Mountain is absent and the Paleocene sequence consists entirely of marine clay, however, no disconformity is known to exist within the massive clay sequence.

The Gravel Creek Member of the updip Nanafalia Formation in western Alabama is a fluvial sand. It is overlain by the *"Ostrea thirsae"* beds and the Grampian Hills Member, both of which were deposited in a restricted marine environment. The Baker Hill Formation, which is the equivalent of the upper Nanafalia in eastern Alabama and western Georgia, was deposited in fluvial and estuarine environments. Downdip, the Nanafalia Formation grades into and becomes part of the massive, marine, undifferentiated Paleocene clay.

The Ellenton Formation is thought to represent a basal shallow marine transgressive deposit that consists in large part of reworked sediments from the underlying Cretaceous. The Beaufort(?) Formation of Gohn and others (1977) consists mostly of marginal marine beds. The overlying Black Mingo Formation is shallow marine for the most part and reflects a slight regression followed by a transgression.

EOCENE SERIES

General

The thick sequence of Eocene rocks that is everywhere present in the study area can be readily divided into rocks of early, middle, and late Eocene age. The rocks mapped during this study as middle Eocene and late Eocene correspond to the Claibornian and Jacksonian provincial Gulf Coast stages, respectively. Rocks of early Eocene age as mapped correspond to the upper part of the Sabinian provincial stage. These relationships are shown on the generalized correlation chart (pl. 2). As the section of this report dealing with the Paleocene Series discusses, the traditionally accepted concept that the Sabinian Stage is equivalent to the Wilcox Group and that both terms refer to rocks of early Eocene age is no longer valid. Many of the units formerly assigned to the lower part of the Sabinian Stage are now known to be of Paleocene age, rather than Eocene (Oliver and Mancini, 1980; Gibson, 1980, 1982a). These units are accordingly included in the Paleocene Series as mapped in this report.

Eocene strata in the study area are extensive, thick, and, where they consist of carbonate rocks, generally highly permeable. The major part of the Floridan aquifer system is made up of Eocene rocks, which commonly show highly developed primary (intergranular) and secondary (dissolution) porosity, particularly in their upper parts. Like the Paleocene rocks, carbonate rocks of both early and middle Eocene age

grade updip by facies change into calcareous, glauconitic, clastic rocks. This carbonate-clastic transition lies farther to the north and west in lower Eocene strata than it does in the underlying Paleocene and is located still farther north and west in middle Eocene rocks. Upper Eocene rocks retain their carbonate character in many places up to the point where they are truncated by erosion. The overall effect is that of a general regional transgression that began in Paleocene time and persisted through the late Eocene and during which the marine facies of progressively younger rocks extended progressively farther and farther inland. Several minor regressions punctuated this general transgression. These observations are consistent with the sea level curve of Vail and others (1977), which shows that sea level worldwide became progressively higher from early to late Eocene time.

Rocks of early Eocene age

Downdip, a lower Eocene carbonate sequence underlies southeastern Georgia and the Florida peninsula; updip, the remainder of the study area is underlain by clastic lower Eocene rocks. Locally, in South Carolina, the Eocene in the subsurface is an impure limestone. Plate 4 shows the configuration of the top of rocks of early Eocene age and the area where they crop out. Comparison of plate 4 with a map of the structural surface of the Paleocene (pl. 3) shows that, in Alabama and southwestern Georgia, lower Eocene rocks lie to the south and east of Paleocene rocks in offlap relationship. In central Georgia, however, beds of early Eocene age overlap and extend farther to the north than the underlying Paleocene rocks. Lower Eocene rocks are known to extend farther to the north in this overlap area than plate 4 shows, but they have been mapped during this study only to the limits of the well control used to delineate the Floridan aquifer system. In the western part of the study area, the configuration of the top of the early Eocene is contoured up to the limit of outcrop of these rocks (pl. 4).

Many of the large- to intermediate-scale structural features that affect the shape of the Paleocene surface (pl. 3) are recognizable on the early Eocene surface (pl. 4). Those features common to both maps include (1) the Peninsular arch in north-central Florida, (2) the Southeast Georgia embayment, and (3) a steep, steady slope toward the Gulf Coast geosyncline in the western part of the study area. The Southwest Georgia embayment in eastern panhandle Florida is a negative area on both the Paleocene and early Eocene tops, but this feature is deeper and narrower and extends farther to the northeast on the early Eocene surface than it does on the top of the Paleocene. The configuration of the South Florida basin in southwestern peninsular Florida likewise differs on the Paleocene and early Eocene surfaces. This feature was somewhat silled on its gulfward side in Paleocene time (pl. 3) but, at the end of early Eocene time (pl. 4) it was open to the gulf and appears to have been partially filled from the east and northeast. The Suwannee strait, a closed low that appears in southeastern Georgia on the map of the Paleocene surface, was apparently filled with sediments during early Eocene time and thus does not exist on the map of the early Eocene surface.

The maximum measured depth to the top of lower Eocene rocks is about 3,900 ft below sea level in well ALA-BAL-30 in the southern part of Baldwin County, Ala. The maximum contoured depth is below 4,200 ft, in the same general area. Lower Eocene rocks are slightly less than 800 ft below sea level on the crest of the Peninsular arch, from which they deepen in all directions. In the Southwest Georgia embayment and the South Florida basin, the top of lower Eocene rocks is below 2,600 ft.

The thickness of lower Eocene strata is shown on plate 5, along with the distribution of the clastic and carbonate facies within this unit. The clastic-carbonate boundary and much of the contouring shown on this plate are derived from well control. In areas of sparse control, the thickness of the early Eocene has been estimated as the difference between contoured altitudes of the top of the early Eocene (plate 4) and the top of the Paleocene (plate 3). In south Florida, lower Eocene rocks are more than 1,500 ft thick; in parts of panhandle Florida, they are more than 1,100 ft thick. On the crest of the Peninsular arch, these strata are less than 300 ft thick, and they thin to a featheredge in areas of outcrop.

Oldsmar Formation—Except for the Fishburne Formation that occurs locally in South Carolina, all the lower Eocene carbonate rocks in the study area are part of the unit that Applin and Applin (1944) named the Oldsmar Limestone. The Oldsmar, however, contains much dolomite, and thin beds of chert and evaporite deposits occur in the unit from place to place. The Oldsmar is therefore referred to as a "formation" rather than a "limestone."

The Oldsmar Formation consists mostly of off-white to light-gray micritic to finely pelletal limestone thickly to thinly interbedded with gray to tan to light-brown, fine to medium crystalline, commonly vuggy dolomite. The lower part of the formation is usually more extensively dolomitized than the upper part. Pore-filling gypsum and thin beds of anhydrite occur in the lowermost parts of the Oldsmar in places, particularly in a crescent-shaped band extending from Dixie County, Fla., northeast to southern Ware County, Ga

The location of this band, which locally comprises the base of the Floridan aquifer system, is shown on plate 33. In scattered places, the Oldsmar contains trace amounts of glauconite.

Applin and Applin (1944, p. 1699) defined the Oldsmar "to include the interval that is marked at the top by the presence of abundant specimens of *Helicostegina gyralis* Barker and Grimsdale...and that rests on the Cedar Keys limestone." This definition is unsatisfactory because (1) it is based on the microfaunal content of the strata, not on their lithologic characteristics, and (2) it is based on a species whose range is not restricted to the early Eocene. The author has found specimens of *H. gyralis* that show no evidence of reworking 50 to 70 ft above the top of the Oldsmar in rocks that are part of the overlying middle Eocene sequence ("Lake City" Limestone). Cole and Gravell (1952) reported this species from middle Eocene beds in Cuba. The Oldsmar Formation is thus redefined herein as the sequence of white to gray limestone and interbedded tan to light-brown dolomite that lies between the pelletal, predominantly brown limestone and brown dolomite of the middle Eocene and the gray, coarsely crystalline dolomite of the Cedar Keys Formation. *H. gyralis* is commonly found as part of a characteristic Oldsmar fauna that includes several other species of larger foraminifers listed in table 1. None of these species, however, is ubiquitous within the Oldsmar Formation, nor should they be the criterion by which the Oldsmar is defined.

The Oldsmar Formation underlies all of the Florida peninsula and the southeastern corner of Georgia (pl. 5). Westward, in the eastern part of the Florida panhandle, the Oldsmar becomes increasingly argillaceous and interfingers with calcareous clastic rocks. To the north, in south-central Georgia, the Oldsmar grades from limestone through argillaceous limestone and calcareous clay into glauconitic calcareous sand.

In addition to *H. gyralis*, the larger Foraminifera *Miscellanea nassauensis* Applin and Jordan, *Pseudophragmina (Proporocyclina) cedarkeysensis* Cole, and *Lockhartia sp.* are considered characteristic of the Oldsmar Formation.

UNDIFFERENTIATED LOWER EOCENE ROCKS—Lower Eocene rocks in the western part of the Florida panhandle consist of brownish- to greenish-gray, calcareous, slightly glauconitic shale and siltstone that are occasionally micaceous. Thin beds of fine-grained, slightly glauconitic sandstone and off-white sandy glauconitic limestone occur sporadically throughout the predominantly argillaceous section. These rocks are part of the unit that was called the "clastic facies of Wilcox age" by Applin and Applin (1944) and the "Wilcox Formation" by Chen (1965). Both Chen and the Applins included beds that are the downdip equivalents of the Nanafalia Formation, the Tuscahoma Formation, and the Salt Mountain Limestone in their "Wilcox" unit. In this report, the Nanafalia, Tuscahoma, and Salt Mountain are considered to be of Paleocene age and to grade downdip into undifferentiated argillaceous rocks of Paleocene age. The term "undifferentiated early Eocene rocks" is herein applied to the massive, predominantly argillaceous early Eocene section of western panhandle Florida. These strata grade eastward into the Oldsmar Formation and become less marine and slightly coarser grained updip in southern Alabama and southwestern Georgia, where they take on the character of the outcropping Hatchetigbee Formation.

Microfauna considered characteristic of undifferentiated rocks of early Eocene age include the Foraminifera *Globorotalia formosa gracilis* Bolli and *Rotalia trochoidiformis* (Lamarck). The Foraminifera *Globorotalia subbotinae* Morozova and *G. wilcoxensis* (Cushman and Ponton) are also considered characteristic of early Eocene rocks in the study area, even though these species are known to range downward into rocks of late Paleocene age elsewhere (Stainforth and others, 1975). The Ostracoda *Brackhcythere jessupensis* Howe and Garrett and *Haplocytheridea sabinensis* (Howe and Garrett) are also considered characteristic of these beds.

BASHI AND HATCHETIGBEE FORMATIONS—The lithology of the Hatchetigbee Formation in the area where it crops out in western Alabama is very similar to that of the underlying Tuscahoma. In practice, the two are difficult to separate except where the sandy, glauconitic, highly fossiliferous Bashi Formation (Gibson, 1982b) lies between them. The Bashi occurs only as erosional remnants in eastern Alabama and western Georgia. Downdip, the Hatchetigbee consists of interbedded fine sand and gray calcareous clay. The sand is lost in a short distance gulfward, and the argillaceous Hatchetigbee beds merge in middip areas with the underlying clay of the Tuscahoma.

UNNAMED MID-GEORGIA LOWER EOCENE ROCKS—In the west-central part of the Georgia coastal plain, lower Eocene rocks consist of medium-grained, calcareous, often dolomitic, glauconitic sandstone interbedded with soft, light-gray, calcareous, glauconitic clay. The sandstone ranges from unconsolidated to well indurated, depending on the amount of calcareous matrix that binds the sand grains. Although these strata are the probable equivalents of the combined Hatchetigbee Formation of eastern Alabama and southwestern Georgia, they are unnamed at present and are not shown on the correlation chart (pl. 2) because their relation to the Hatchibtigbee is still inexactly known.

These unnamed lower Eocene sand and clay beds become progressively more argillaceous and calcareous downdip to the southeast and grade into an off-white, micritic, glauconitic, argillaceous limestone that commonly contains the foraminifer *Pseudophragmina (Proporocyclina) cedarkeysensis* Cole, a species that is found in the Oldsmar Formation in Florida. This micritic limestone, unnamed at the time of this writing, grades seaward over a short distance into a typical Oldsmar lithology. Updip, the lower Eocene clay beds are lost, and the sands become progressively less marine until they grade into a predominantly fluvial thick sand sequence that may be part of the Huber Formation (Huddlestun, 1981).

In easternmost Georgia, lower Eocene rocks consist mostly of calcareous, glauconitic, argillaceous sand, cream to gray calcareous clay, and sandy, glauconitic limestone. Locally, some of the clayey beds are dark brown and silty and contain much fine-grained organic material. Northeastward, in South Carolina, lower Eocene strata consist of sandy, fossiliferous, glauconitic limestone that has recently been named the Fishburne Formation (Gohn and others, 1983).

Depositional environments—Most of the lower Eocene rocks in the study area were deposited in shallow open marine to marginal marine environments. The laminated silty sands of the Hatchetigbee Formation were deposited in a restricted marine area, probably on tidal flats. Periodically, slightly deeper marine waters covered the tidal flats, and the Bashi Formation was deposited during such a local short-lived transgression.

Seaward of this marginal marine area, the undifferentiated thick sequence of fine clastic rocks of early Eocene age was deposited in quiet, shallow to moderately deep, open marine waters in the area that is now western panhandle Florida. Open marine conditions characterized by slightly higher energy levels existed in the central part of the Georgia coastal plain during early Eocene time, and an interbedded sequence of marine sand and clays was deposited there. This sequence, unnamed at present, grades laterally to the northeast into shallow marine sandy limestone that represents the Fishburne Formation of South Carolina.

Both the shallow water, open marine, clastic lower Eocene strata of central Georgia and the deeper water, massive clay sequence of panhandle Florida grade into and interfinger with the Oldsmar Formation. The Oldsmar was deposited in warm, shallow, open marine water and represents a carbonate bank environment. The minor evaporites found occasionally in the lower part of the Oldsmar represent sabkha conditions that were short lived and not areally extensive.

Rocks of middle Eocene age

Middle Eocene strata are present over almost all of the study area and can generally be divided into a downdip platform carbonate facies and an updip facies that is predominantly clastic. The carbonate facies of the middle Eocene extends much farther to the north and west than the carbonate rocks of the underlying early Eocene. Approximately half of the Georgia coastal plain, much of the eastern part of the Florida panhandle, and all of the Florida peninsula are underlain by middle Eocene carbonate rocks. In the remainder of the study area, the middle Eocene consists of marine to marginal marine clastic rocks.

The configuration of the top of the middle Eocene and the area where this unit crops out are shown on plate 6. Middle Eocene rocks in Alabama and southwestern Georgia are located farther gulfward than underlying rocks of early Eocene age. In contrast to this offlap relation, the lower Eocene is overlapped by middle Eocene strata in central Georgia and in South Carolina. The top of the middle Eocene is contoured to the point where the unit pinches out in its outcrop area but only to the limit of well control in eastern Georgia and South Carolina. In these areas, the middle Eocene is mostly overlapped by younger rocks.

The effect of several large-scale structural features is reflected on the middle Eocene surface. Although many of these features are recognizable on maps of the tops of older units (pls. 3, 4), their locations and shapes are different on the middle Eocene map (pl. 6). The Peninsular arch is poorly defined on plate 6, and its surface is highly irregular, probably as a result of erosion and dissolution of the top of the middle Eocene. The top of middle Eocene strata in this area is generally higher than 200 ft below sea level. The Southeast and Southwest Georgia embayments and the South Florida basin are present as low areas on the middle Eocene top, but they are not as pronounced as they are on the maps of older units. These basins were probably relatively quiescent and were being filled during middle Eocene time. The Gulf Coast geosyncline was actively subsiding during the middle Eocene, as the steep, steady gulfward slope of the top of the unit in western panhandle Florida shows. The configurations of the unnamed negative area in east-central Georgia and of the high area parallel to it in southeastern South Carolina are similar on the middle Eocene top to those on older units.

Several faults of small to intermediate throw first occurred during middle Eocene time (pl. 6). Unlike the large-displacement faults in southwestern Alabama that affect the entire column of rocks mapped for this study, most of the faults shown on plate 6 in central

Georgia and peninsular Florida appear to die out downward within the middle Eocene. An exception is the fault in Palm Beach County, Fla., which cuts rocks at least as old as Paleocene (pl. 3). The series of northeast-trending faults in south-central Georgia bounds several small grabens and half grabens that are collectively called the Gulf Trough (Herrick and Vorhis, 1963). Like most of the faults in peninsular Florida, the Gulf Trough faults appear to die out at shallow depths. A seismic profile was obtained across one of the major Gulf Trough faults in northeastern Colquitt County, Ga., as part of this study. The record on this profile is poor down to a depth of approximately 1,200 ft below land surface. Deeper than about 1,300 ft (roughly the middle of rocks of middle Eocene age), however, sharp reflectors can easily be traced on the profile and do not show the graben structure that well data prove to exist at shallower depths.

The maximum measured depth to the top of the middle Eocene is 3,490 ft below sea level in well ALA-BAL-30 in southwestern Baldwin County, Ala. The maximum contoured depth is below 3,700 ft in the same area (pl. 6). The top of the middle Eocene slopes in all directions from the crest of the Peninsular arch and reaches depths of more than 1,800 ft in the Southwest Georgia embayment, more than 1,600 ft in the South Florida basin, and more than 1,000 ft in the Southeast Georgia embayment. Middle Eocene rocks are slightly above sea level at scattered places on the Peninsular arch. They are exposed at the surface in Citrus and Levy Counties, Fla., where they represent the oldest outcropping rocks in the state.

The thickness of middle Eocene rocks is shown on plate 7, which also shows the limits of the unit's clastic and carbonate facies. The position of the interface between these facies is approximate because it is based on well control. The thickness trends shown on plate 7 have been extended in areas where well control is scattered by subtracting the contoured tops of rocks of early and middle Eocene age. From a featheredge in outcrop areas, the middle Eocene thickens seaward to more than 1,200 ft in the Southwest Georgia embayment and to more than 1,000 ft in southeastern Georgia. Along panhandle Florida's Gulf Coast, these strata are more than 900 ft thick. They thin to less than 500 ft over the crest of the Peninsular arch and thicken southward to more than 1,600 ft in east-central peninsular Florida. Although the middle Eocene is between 1,000 and 1,400 ft thick in most of southern Florida, the unit thins to less than 900 ft in part of the South Florida basin, and shows that this basin was not subsiding rapidly during middle Eocene time.

Avon Park Formation—Applin and Applin (1944, p. 1686) applied the name Avon Park Limestone to the upper part of the late middle Eocene section in a well at the Avon Park Bombing Range in the southernmost part of Polk County, Fla. They referred to the Avon Park as "a distinct faunal unit" and described it as "mainly cream-colored, highly microfossiliferous, chalky limestone" that locally contains some gypsum and chert and that is commonly partially dolomitized. Well cuttings examined during this study show that the Avon Park is in many places composed almost entirely of dolomite. The Avon Park is thus referred to in this report as a "formation" rather than a "limestone."

The term Lake City Limestone was introduced by Applin and Applin (1944, p. 1693) for the lower part of rocks of middle Eocene age in a well at Lake City in Columbia County, Fla. The Lake City was described as "alternating layers of dark brown and chalky limestone"; gypsum and chert are present in some wells. Regionally, the lower part of the middle Eocene, like the upper part, contains much dolomite.

In the early 1940's, there were few deep wells in Florida, and the samples from many of these wells were either contaminated or incomplete. Electric logging was a new technique at the time, and those few logs that were in existence were largely unreliable. A common practice in subsurface stratigraphy was to use paleontologic and lithologic units interchangeably. All of these factors led to imprecise definitions for most of the limestone units of Florida. Between some adjacent "formations," lithologic change is subtle; in places, there is no change at all. Stratigraphic breaks in much of the Florida section currently are based upon a change in the benthic microfauna that the rocks contain. Where dolomitization has obliterated the microfauna, or where it is lacking in nondolomitized sections, correlations are inconsistent. Although most workers studying the Florida subsurface recognize the problem, almost all Tertiary limestone correlations are still made on the basis of the microfaunal assemblages that Applin and Applin (1944) and Applin and Jordan (1945) thought were diagnostic. This practice is, of course, not in accordance with the rules of the current North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Units that are in reality biostratigraphic units have been mapped as if they were rock-stratigraphic units. Fortunately, as Winston (1976), recognized, the paleontologically defined units of Applin and Applin (1944) in many cases coincide with lithologic units. Exceptions to this generalization are the Avon Park and Lake City Limestones.

There are no lithologic criteria that can be used to separate the middle Eocene carbonate rocks in Florida and in southern Georgia. Both the so-called Avon Park and Lake City Limestones consist primarily of

cream, tan, or light-brown, soft to well-indurated limestone that is mostly pelletal but is locally micritic. The pellets consist of fine to coarse sand-sized particles of micritic to fine crystalline limestone and small- to medium-sized Foraminifera; they are bound by a micritic to finely crystalline limestone matrix. The limestone is thinly to thickly interbedded with cream or light- to dark-brown, fine to medium crystalline, slightly vuggy dolomite, fractured in some places, whose texture is locally sucrosic to argillaceous. Locally, differences exist between the general lithologic character of the lower part of the middle Eocene and that of its upper part. Unfortunately, two of the limited number of wells available to the Applins (the Avon Park Bombing Range and Lake City wells) showed such contrasts, and it was on the basis of the limited data then available that the Avon Park and Lake City were named and extended regionally. More recent drilling shows conclusively that the rock types that the Applins thought were representative of their "Lake City" are found in many places at the top of the middle Eocene (in their "Avon Park" part) and the reverse is also true.

Paleontologic criteria by which the Avon Park and Lake City can be differentiated are lacking. In the original definition of both the Avon Park and the Lake City, certain faunal zones by which these units could be recognized were listed. The Lake City was thought to extend from the highest occurrence of *Dictyoconus americanus* (Cushman), accompanied by *Fabularia vaughani* Cole and Porter, down to the highest occurrence of *Helicostegina gyralis* Barker and Grimsdale, thought to characterize the Oldsmar. None of these species is restricted to the horizon for which it is supposed to be characteristic. *H. gyralis* commonly occurs several hundred feet above a typical Oldsmar lithology. In this study, *Fabularia vaughani* has been found at or just below the top of the middle Eocene—in the "Avon Park" part. *Dictyoconus americanus* has been reported by Cole (1944, 1945) and by Vernon (1951) from the upper part of the middle Eocene. The author has found several additional species that were listed as diagnostic Lake City Foraminifera by Applin and Jordan (1945) within 20 to 50 feet of the top of the uppermost middle Eocene. These species include *Discorbis inornatus* Cole, *Fabularia gunteri* Applin and Jordan, and *Gunteria floridana* Cushman and Ponton. Cole and Gravell (1952) found several supposedly diagnostic Lake City species in the same beds as supposedly diagnostic Avon Park species in the outcropping middle Eocene of Cuba. The Avon Park was originally defined by Applin and Applin (1944) as extending from the highest occurrence of *Coskinolina floridana* Cole downward to the top of *Dictyoconus americanus*. As Applin and Applin (1944, p. 1687), recognized, however, that *Coskinolina floridana* is abundant in the Oligocene Suwannee Limestone in many places.

The so-called Avon Park and Lake City Limestones cannot be distinguished from each other on the basis of either lithology or fauna, except locally. Therefore, it is here proposed that the term "Lake City" be abandoned and that all of the cream to brown pelletal limestone and interbedded brown to cream dolomite of middle Eocene age in peninsular Florida and southern Georgia be placed in the Avon Park Formation. The term "Avon Park" is retained because (1) it has precedence over the term "Lake City," (although both the Avon Park and the Lake City were named in the same report by Applin and Applin (1944), the Avon Park was described on an earlier page in that paper) and (2) the term has traditionally been applied to rocks whose lithology is different from that of the overlying Ocala Limestone. The Avon Park is more properly called a "formation" rather than a "limestone" because it contains appreciable amounts of rock types other than limestone. The extended definition of the Avon Park Formation proposed here refers to the sequence of predominately brown limestones and dolomites of various textures that lies between the gray, largely micritic limestones and gray dolomites of the Oldsmar Formation and the white foraminiferal coquina or fossiliferous micrite of the Ocala Limestone.

The reference section proposed for the extended Avon Park Formation is the interval from 221 to 1,190 ft below land surface in the Coastal Petroleum Company's No. 1 Ragland well in sec. 16, T. 15 S, R. 13 E, in Levy County, Fla. Cuttings from this well are on file at the Florida Bureau of Geology, Tallahassee, Fla., as well W-1537 or permit number 66. The well is numbered FLA-LV-4 in this report. A lithologic description of the cuttings from the proposed type well is given in the Appendix of this report. The top of the Avon Park is not known in the type well because there is a gap in the cuttings from the basal Ocala at a depth of 110 ft to the uppermost Avon Park sample at 221 ft. Figure 5 shows a representative electric log pattern for the Avon Park Formation (extended) in a nearby well in Levy County, Humble's No. 1 C. E. Robinson (well FLA-LV-5 of this report).

Fauna considered characteristic of the revised Avon Park Formation include the Foraminifera *Spirolina coreyensis* (Cole), *Lituonella floridana* (Cole), *Discorbis inornatus* Cole, *Valvulina cushmani* Applin and Jordan, *V. martii* Cushman and Bermudez, *Fabularia vaughani* Cole and Ponton, *Textularia coreyensis* Cole, *Gunteria floridana* Cushman and Ponton, *Pseudorbitolina cubensis* Cushman and Bermudez, *Amphistegina lopeztrigoni* Palmer, and *Lepidocyclina antillea* Cushman (formerly called *L. gardnerae* Cole). Fragments of the alga *Clypeina infundibuliformia* Moreile

and Morellet are also considered characteristic of the Avon Park.

To the north and west, the Avon Park Formation grades into an argillaceous, soft to semi-indurated, micritic, glauconitic limestone that in turn grades updip into calcareous, glauconitic, often shelly sand and clay beds that are parts of the Lisbon and Tallahatta Formations. The middle third of the revised Avon Park Formation in the eastern half of the Florida peninsula and in much of southeastern Georgia is micritic, low-permeability, finely pelletal limestone. Approximately the lower half of the extended Avon Park in west-central peninsular Florida consists of low-permeability dark-colored gypsiferous limestone and dolomite. Both the micritic limestone and the gypsiferous carbonate beds comprise important subregional confining units within the Floridan aquifer system.

TALLAHATTA FORMATION—Where the Tallahatta Formation crops out in western Alabama, it consists largely of greenish-gray, porous, fine-grained siliceous claystone (called buhrstone in older reports) and some interbedded sands that are calcareous and fossiliferous near the top of the unit. In eastern Alabama, the outcropping Tallahatta is mostly poorly sorted, occasionally gravelly sand interbedded with greenish-gray clay and calcareous sand near the top. In southwestern Georgia, the outcropping Tallahatta is somewhat more marine than it is in Alabama and consists of fine- to coarse-grained slightly fossiliferous sand interbedded with dark-brown, silty, micaceous, occasionally glauconitic limestone. Chert is common near the base of the Tallahatta in updip areas in Georgia.

Downdip, in both Alabama and Georgia, the Tallahatta consists largely of interbedded gray to greenish-gray glauconitic sand and greenish-gray to brownish-gray shale; light- to dark-brown glauconitic fossiliferous limestone is common. Farther seaward in Georgia, the Tallahatta grades into cream to light-gray glauconitic, argillaceous, somewhat sandy limestone that in turn grades into the revised Avon Park Formation. Along and just to the north of the Gulf Coast of Alabama and western panhandle Florida, the Tallahatta consists mostly of gray to greenish-gray clay and thin to moderately thick interbeds of fine-grained, glauconitic, calcareous sand. Neither the limestone facies nor the calcareous clay and sand of western Florida and southern Alabama can be distinguished from similar overlying strata that are considered to be the Lisbon Formation in this study. In northeastern Georgia, the Tallahatta is mostly gray, calcareous, fossiliferous clay and has a thin sequence of calcareous sand and glauconitic limestone at the base. These strata grade northeastward into calcareous shelly sand

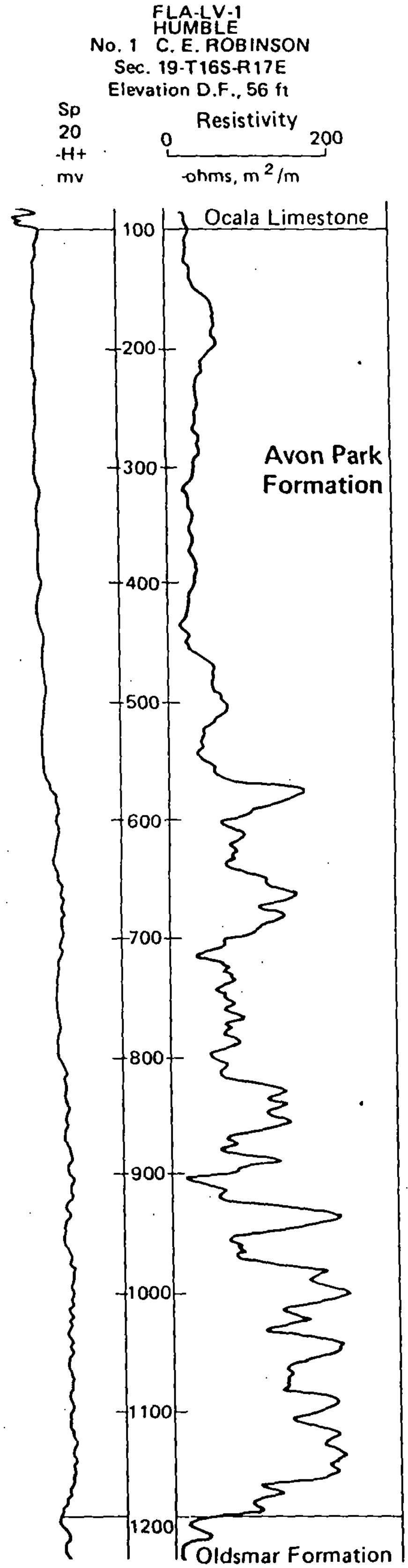


Figure 5. Representative electric log pattern for the Avon Park Formation.

and clay beds that are parts of the Congaree Formation and the Warley Hill Marl of South Carolina.

LISBON FORMATION—In its outcrop area in southwestern Alabama, the Lisbon Formation consists of interbedded calcareous, glauconitic sand, sandy clay, and clay, all of which are dark green to greenish gray and fossiliferous. Carbonaceous clays commonly occur near the middle of the Lisbon in this area. In central Alabama, the outcropping Lisbon is mostly sand. Farther eastward, in southeastern Alabama and southwestern Georgia, the composition and appearance of Lisbon in outcrop are similar to those of the Lisbon in southwestern Alabama, except that the strata are somewhat lighter in color. Downdip, in southern Alabama and panhandle Florida, the Lisbon grades into gray, greenish-gray, or light-brown calcareous, glauconitic clay that contains thin to thick beds of fine-grained, calcareous, glauconitic sand and hard, sandy, glauconitic limestone. In this area contiguous to the Gulf Coast, the Lisbon cannot be differentiated from the Tallahatta.

To the east, the undifferentiated Lisbon-Tallahatta sequence grades into light-gray, glauconitic, argillaceous, somewhat sandy limestone that in turn grades into the Avon Park Formation. This light-colored, fine-grained limestone is also found throughout Georgia in a middip position between the calcareous clastic rocks of the outcropping or updip Lisbon and the pelletal Avon Park Formation. Like the Lisbon-Tallahatta sequence along the Gulf Coast, this limestone facies cannot be split into "Tallahatta" and "Lisbon" components.

In northeastern Georgia, the Lisbon consists mostly of light-gray argillaceous limestone and is underlain by clastic strata that are Tallahatta equivalents. To the northeast, the lower part of the argillaceous limestone becomes sandy, fossiliferous, and glauconitic and grades into the Warley Hill Marl of South Carolina. The upper part of the argillaceous limestone grades into the Santee Limestone of South Carolina, a slightly coarser, soft, cream to yellow, fossiliferous limestone that contains minor beds of glauconitic sand and clay.

Fauna considered characteristic of the undifferentiated clastic Lisbon-Tallahatta sequence in the study area include the Foraminifera *Asterigerina texana* (Stadnichenco), *Ceratobulimina stellata* Bandy, and *Globorotalia bullbrooki* Bolli. The ostracode *Leguminocythereis petersoni* Swain is also commonly found in these clastic middle Eocene strata.

GOSPORT SAND—In western Alabama, the uppermost part of the middle Eocene sequence consists of fine- to coarse-grained, glauconitic, fossiliferous sand and some beds of dark-colored shale. This unit, called the Gosport Sand, is thought to be local because it is not recognizable either in outcrop in central Alabama or in downdip wells. The strata called "Gosport" in the Savannah, Ga., area by Counts and Donsky (1963) are included in the undifferentiated Lisbon-Tallahatta sequence of this report because their lithology is completely unlike that of the Gosport even though their stratigraphic position is the same.

MCBEAN FORMATION—In northeast Georgia and in South Carolina, fine-grained, loose to semiconsolidated, slightly fossiliferous sand of middle Eocene age occurs locally. This sand, called the McBean Formation, grades downward and seaward into calcareous clay that in turn grades into the upper part of the Santee Limestone. Like the Gosport, the McBean is of only local importance in the study area.

DEPOSITIONAL ENVIRONMENTS—The outcropping Tallahatta and Lisbon Formations were deposited in shallow marine to marginal marine environments. Transgression of the sea during the middle Eocene was more extensive than it was during either Paleocene or early Eocene time. Shallow marine Lisbon-Tallahatta rocks extending to the shore of the present Gulf of Mexico show that the middle Eocene sea floor sloped very gently there and that shallow marine waters extended over a wide area.

The Avon Park Formation, like the Oldsmar and Cedar Keys Formations, was deposited on a shallow, warm-water carbonate bank. Some of the evaporites that characterize the lower parts of the revised Avon Park Formation in west-central peninsular Florida may have formed in a tidal flat or sabkha environment.

The Congaree, Warley Hill, and Santee beds of South Carolina were deposited as the result of a single continuous transgression (Pooser, 1965). The Congaree represents basal clastic deposits. The Warley Hill was laid down in very shallow marine waters, and the Santee was deposited in a shallow shelf, open marine environment.

The Gosport Sand represents a regressive shallow marine to marginal marine deposit that was laid down as the middle Eocene sea withdrew. The McBean likewise represents a regressive sand.

ROCKS OF LATE EOCENE AGE

Upper Eocene rocks underlie practically all of the study area, except for local areas in peninsular Florida where they have been removed by erosion. In contrast with older Tertiary units, strata of late Eocene age consist of carbonate rocks throughout all of the study area except (1) in updip outcrop locales where they

interfinger with clastic materials or have been weathered into a clayey residuum and (2) in western Alabama and much of the Florida panhandle, where the upper Eocene section consists mostly of fine clastic sediments. The late Eocene represents the most extensive and widespread transgression of Tertiary seas in the Southeastern United States.

The extent, configuration of the top, and area of outcrop of rocks of late Eocene age are shown on plate 8. In Alabama and the southwesternmost corner of Georgia, these rocks are found farther gulfward than the middle Eocene strata that they overlie in offlap relation. From Stewart County, Ga., northeast, however, upper Eocene strata overlap older beds. This onlap relation extends into part of South Carolina.

From an altitude of more than 400 ft above sea level in their area of outcrop in Georgia and South Carolina, upper Eocene beds generally slope gently seaward (pl. 8). This slope is interrupted in northern peninsular Florida by a widespread high area upon which the top of upper Eocene rocks rises to altitudes slightly above sea level. This high area has been called the Ocala uplift, but it is not a true uplift. Even though this feature appears as a high on the upper Eocene top, it is not a structural high on the tops of older units (compare pl. 8 with pls. 3, 4, and 6). The upper Eocene may be high on the Ocala "uplift" because of either (1) deposition of an anomalously thick section of upper Eocene rocks in this area, (2) differential compaction, or (3) postdepositional erosion. The Ocala "uplift," regardless of its origin, is not related to the Peninsular arch. The fact that the effect of the Peninsular arch is not apparent on maps of the top of upper Eocene or younger rock shows that the arch ceased to be an active structure after middle Eocene time.

Some of the major structural lows in the study area, however, continued to actively subside during late Eocene time. Plate 8 shows a steep slope on the upper Eocene top in westernmost panhandle Florida and southern Alabama that reflects the influence of the Gulf Coast geosyncline. The negative area in Gulf and Franklin Counties in panhandle Florida is the Southwest Georgia embayment, and the low centered in Glynn County, Ga., is the Southeast Georgia embayment. The South Florida basin is also shown on plate 8 as a low area in southwestern peninsular Florida. The poor definition of the unnamed low area in east-central Georgia and its contiguous high in South Carolina (pl. 8) indicate that these features were not active "warps" in the late Eocene.

There are a number of small- to medium-sized faults shown on plate 8 that first occur in the late Eocene. Most of these are in central and northern peninsular Florida. Like the Gulf Trough graben system (running northeast across central Georgia on pl. 8), which affects only middle Eocene and younger rocks, these faults in central and northern Florida appear to be shallow features that die out with depth. The locations of the small faults are better known, and the topography shown on plate 8 for the upper Eocene top is more deatailed than that shown for deeper horizons because upper Eocene strata provide a prolific source of ground water and are therefore more intensively drilled than older units.

Upper Eocene rocks crop out more extensively than any other Tertiary unit except the Miocene. In much of their updip outcrop area, they consist largely of calcareous clastic rocks. In southwestern Georgia, easternmost Alabama, and contiguous counties in Florida, uppermost Eocene rocks consist of soft to well-indurated limestone that has a thin to moderately thick (less than 10 to more than 50 ft) clayey residuum developed on it. This residuum masks and subdues the karst topography that drilling shows is developed on the limestone surface there. In western peninsular Florida, upper Eocene sediments consist mostly of highly fossiliferous, soft limestone that shows a highly irregular, karstic, often cavernous surface resulting from extensive dissolution of the rock. Locally, in parts of the Florida peninsula, upper Eocene rocks have been completely removed by erosion, and rocks of middle Eocene age are exposed through the late Eocene surface (pl. 8).

The maximum measured depth to the top of the upper Eocene is about 3,380 ft below sea level in well ALA-BAL-30 in southern Baldwin County, Ala. The maximum contoured depth is about 4,000 ft, just to the southwest of this well. The top of rocks of late Eocene age is more than 1,000 ft below sea level in the Southwest Georgia embayment, more than 700 ft in the Southeast Georgia embayment, and more than 1,200 ft in the South Florida basin. In north-central Florida, the upper Eocene top is at or slightly above mean sea level over a wide area and slopes seaward in all directions from this high. Locally, the upper Eocene top has been vertically displaced as much as 300 ft across some of the small faults that cut the unit.

The thickness of upper Eocene strata is shown on plate 9. In contrast with older Tertiary units, upper Eocene beds are comprised of carbonate rocks almost everywhere. Most of the contouring on plate 9 is based on well-point data. In areas of sparse well control, the thickness of rocks of late Eocene age has been estimated by subtracting contoured structural surfaces of the middle and upper Eocene (pls. 6, 8). The upper Eocene is generally 200 to 400 ft thick, with two major exceptions. In the Southwest Georgia embayment, these rocks are more than 800 ft thick, and in the central

part of peninsular Florida, they are less than 100 ft thick in an area that trends east-west across the peninsula. There is much local variation in the thickness of the upper Eocene because of the effects of erosion and (or) dissolution of these rocks, especially in and near the places where they crop out.

Ocala Limestone—Dall and Harris (1892) applied the name Ocala Limestone to the limestone exposed in quarries near Ocala in Marion County, Fla. These rocks were incorrectly correlated with strata in Alabama that were thought then to be Eocene but that are now known to be of Oligocene age. Cooke (1915) was the first to assign the Ocala to its correct upper Eocene stratigraphic position. Applin and Applin (1944) divided the Ocala into upper and lower members. This twofold division of the formation is still used by the U.S. Geological Survey at the time of this writing (1984). However, the Florida Bureau of Geology considers the Ocala to be a group consisting of, in ascending order, the Inglis, Williston, and Crystal River Formations, as Puri (1953b) proposed.

Puri's three formations cannot be recognized lithologically even at their type sections and cannot be differentiated in the subsurface. This author does not consider the Inglis, Williston, and Crystal River Formations to be either readily recognizable nor mappable, and the terms are not used in this report. As Applin and Applin (1944) recognized, the Ocala consists in many places of two different rock types. The upper part of the Ocala is a white, generally soft, somewhat friable, porous coquina composed of large Foraminifera, bryozoan fragments, and whole to broken echinoid remains, all loosely bound by a matrix of micritic limestone. This coquina is the typical Ocala of the literature and comprises much of the formation. The lower part of the Ocala consists of cream to white, generally fine grained, soft to semi-indurated, micritic limestone containing abundant miliolid remains and scattered large foraminifers. Locally, in southern Georgia, the lower part of the Ocala is slightly glauconitic. This lower fine-grained facies of the Ocala is not everywhere present and may locally be dolomitized wholly or in part. In southern Florida, the entire Ocala is composed of micritic to finely pelletal limestone in places. Because the twofold division of the Ocala is not everywhere recognizable and because the lower micritic unit is thin where it occurs, the two members are not differentiated in this report.

The Ocala Limestone is found throughout Florida (except where it has been locally removed by erosion) and underlies much of southeastern Alabama and the Georgia coastal plain. The Ocala is one of the most permeable rock units in the Floridan aquifer system. The surface of the formation is locally very irregular as a result of the dissolution of the limestone and tl development of karst topography. Locally, the upp few feet of the Ocala in the subsurface consist of whit soft, clayey residuum. Where the formation is expose at the surface, such residuum may also be present (a in southwestern Georgia), but the clayey material ocher to red there owing to the oxidation of the sma amounts of iron that it contains.

Fauna considered characteristic of the Ocala Lim stone include the Foraminifera *Amphistegina pinarei sis cosdeni* Applin and Jordan, *Lepidocyclina ocalan* Cushman, *L. ocalana floridana* Cushman, *Eponide jacksonensis* (Cushman and Applin), *Gyroidina cry talriverensis* Puri, and *Operculina mariannens* Vaughn. Although the foraminiferal genus *Asteroc clina* is not restricted to the late Eocene, it usually not found above the top of the Ocala in the study are The Ostracoda *Cytheretta alexanderi* Howe and Char bers and *Jugosocythereis bicarinata* (Swain) are four in shallower water parts of the Ocala as well as in i clastic equivalents.

Moodys Branch Formation—In western panhand Florida, the Ocala thins and, although the upper pa of the formation retains its typical coquinoid chara ter, the lower part grades westward into soft gray cl and minor interbedded fine-grained sand. This lithol gy is correlative with the outcropping Moodys Bran Formation of western Alabama, which consists greenish-gray, calcareous, glauconitic sand and cl and a few layers of sandy limestone.

Yazoo Clay—The upper part of the Ocala in cent Alabama grades northward and westward through white, massive, fine-grained, clayey, glauconitic lin stone into the outcropping Yazoo Clay in weste Alabama and eastern Mississippi. The Yazoo can locally divided into four members (Murray, 194 (from oldest to youngest): (1) the North Twistwo Creek Clay, a bluish-gray, sandy, slightly calcareo fossiliferous clay; (2) the Cocoa Sand, a yellowish-gr fine- to medium-grained, massive, fossiliferous sa (3) the Pachuta Marl, a light greenish-gray, clay fossiliferous, calcareous sand or sandy limestone; a (4) the Shubuta, a light-gray to white, calcareo fossiliferous, sandy clay. These divisions of the Ya can be traced in the subsurface for only a short tance downdip from their area of outcrop.

Fauna considered to characterize the Yazoo Clay, middip equivalents, and the basal clastic part of Ocala in the Florida panhandle include the Forami era *Bulimina jacksonensis* Cushman, *Robulus gutti status cocoaensis* (Cushman), and *Globigerina trip tita* Koch. Ostracoda that characterize these b include *Cytheretta alexanderi* Howe and Chamb

Clithocytheridea caldwellensis (Howe and Chambers), *C. garretti* (Howe and Chambers), *Jugosocythereis bicarinata* (Swain), and *Haplocytheridea montgomeryensis* (Howe and Chambers). The latter species ranges downward into middle Eocene beds but does not occur above the top of the upper Eocene.

BARNWELL FORMATION—The lower part of the Ocala Limestone grades laterally into more clastic rocks in northeastern Georgia. In the Savannah area, much of the lower part of the Ocala consists of light-brown, highly sandy, glauconitic, argillaceous limestone. This unit, unnamed at present, grades in turn to the north into the outcropping Barnwell Formation of eastern Georgia and southwestern South Carolina. The updip Barnwell consists of fine- to coarse-grained, gray, yellow, pink, and red arkosic sand and thin beds of light-gray to green, glauconitic, fossiliferous clay.

In parts of eastern Georgia, the Barnwell is divided into (1) a thin and locally occurring basal sand (possibly equivalent to the Clinchfield Sand), (2) a green to gray, sandy, locally glauconitic clay member (Twiggs Clay Member), and (3) an upper, massive, red, medium- to coarse-grained, locally clayey sand (Irwinton Sand Member). The Clinchfield sand and the members of the Barnwell Formation can be traced only a short distance downdip, where they grade into calcareous, argillaceous rocks that in turn grade seaward into the lower part of the Ocala Limestone.

COOPER FORMATION (LOWER MEMBERS) AND EQUIVALENT ROCKS—The upper part of the Ocala grades northward, by the addition of calcareous clay and the loss of large foraminifers, into a soft, white, argillaceous, sandy, slightly glauconitic, bryozoan-rich limestone that is the basal part of the Cooper Formation of South Carolina and northeastern Georgia. In South Carolina, the Cooper is divided into three members (Ward and others, 1979), the lower two of which are of late Eocene age. The uppermost member of the Cooper is of Oligocene age and is discussed in the Oligocene section of this report.

The basal Harleyville Member of the Cooper is a soft, clayey, micritic limestone that contains small amounts of glauconite and pyrite. A phosphate-pebble conglomerate is commonly found at the base of the Harleyville Member. The middle unit of the Cooper is the Parkers Ferry Member, a glauconitic clayey limestone that is highly fossiliferous. The Parkers Ferry Member represents the uppermost part of the late Eocene in South Carolina. The Cooper Formation is not subdivided in Georgia. Most of the Cooper in outcrop and in the shallow subsurface of Georgia is lithologically similar to the Parkers Ferry Member of South Carolina.

The updip equivalent of the Cooper Formation in Georgia is a medium- to coarse-grained, locally argillaceous and pebbly, massive red to reddish-brown sand. This unit, called the Tobacco Road Sand by Huddlestun and Hetrick (1978), is thought to be a marginal marine (lagoonal or estuarine) equivalent of the Cooper Formation. The Tobacco Road is of local importance only and is not recognizable in the subsurface.

Few cores or cuttings from wells that penetrated either the Barnwell Formation or the Cooper Formation and its equivalents were examined during this study. Although these strata are known to contain a sparse to well-developed microfauna in places, no species has been identified during this study as being characteristic of these formations.

DEPOSITIONAL ENVIRONMENTS—Practically all the rocks of late Eocene age in the study area were deposited in shallow, open to marginal marine environments. The Ocala Limestone was deposited in warm, shallow, clear water on a carbonate bank that was probably similar to the modern Bahama Banks. The basal part of the Ocala in western panhandle Florida and the Moodys Branch Formation, which is its updip equivalent, as well as the Yazoo Clay represent marginal marine (lagoon or estuary) to shallow, open-shelf conditions.

The Barnwell Formation and the Tobacco Road Sand were deposited in estuarine, sound, or lagoonal conditions. The Cooper Formation that lies downdip from these units represents shallow water, open marine conditions. The basal phosphate conglomerate of the Harleyville Member of the Cooper was deposited during transgression of the late Eocene sea.

OLIGOCENE SERIES

Rocks of Oligocene age are found over approximately two-thirds of the study area and occur in two separate large bodies. The more extensive area underlain by Oligocene rocks is a wide band that extends seaward from the outcrop of these rocks in Alabama, Georgia, and South Carolina. A second, somewhat smaller area of Oligocene strata covers the southwestern quarter of the Florida peninsula. Plate 10 shows the extent of these two main bodies of Oligocene rocks, the area where Oligocene strata crop out, and the configuration of the Oligocene surface. Throughout the study area, Oligocene rocks are in offlap relation to the upper Eocene and lie seaward of these older beds (compare pls. 8 and 10). Where Oligocene rocks are overlapped by Miocene sediments, the updip limit of the Oligocene is approximate because it is based on available well data; this approximate limit is shown as a dashed line on plate 10. The Oligocene Series con-

sists of carbonate rocks throughout all of the study area except for southwestern Alabama, western panhandle Florida, and parts of northeastern Georgia and southwestern South Carolina, where clastic strata make up an important part of the Oligocene. The few scattered outliers of Oligocene lying between the two main bodies shown on plate 10, indicate that these rocks extended over a much wider area before being removed by erosion. Older rocks are exposed at scattered places within the widespread but generally thin body of the Oligocene in Georgia, where erosion has removed all of the Oligocene locally. The locations of most of the Oligocene outliers and the places where Oligocene rocks have been stripped are based on well data compiled for this study. A few of these features, however, are located from published sources, and thus lie in places where no well control is shown on plate 10. Erosional remnants to the north and west of the general updip limit of the Oligocene show that these rocks once extended over a much wider area.

Both large- and small-scale structural features affect the configuration of the Oligocene top. Large-scale features include (pl. 10) (1) the steep gulfward slope of the unit in southwestern Alabama, which reflects subsidence of the Gulf Coast geosyncline, (2) the low area in southern Gulf County, Fla., that represents the Southwest Georgia embayment, (3) the negative area in Glynn County, Ga., and adjacent counties that is the Southeast Georgia embayment, and (4) a low area in southwestern peninsular Florida that may represent a remnant of the South Florida basin. The northwest-southeast orientation of the axis of the South Florida basin is different from its alinement on the surface of older rock units (compare, for example, pls. 8 and 10). The high area shown on the Oligocene surface along the Gulf of Mexico parallel to the South Florida basin is not present on the upper Eocene top. This high probably acted as a sill or barrier during Oligocene time and partly restricted open circulation between the South Florida basin and the ocean. Smaller structural features shown on plate 10 include the northeast-trending series of small grabens in central Georgia that are collectively called the Gulf Trough and a coast-parallel normal fault that extends from Indian River County southeast through Martin County, Fla. The Oligocene has been eroded from the upthrown side of this fault but is preserved on its downthrown side.

The Oligocene top slopes generally seaward from a high of more than 300 ft above sea level in the unit's outcrop area in central Georgia to slightly more than 600 ft below sea level in both the Southwest and Southeast Georgia embayments. This general seaward slope is interrupted in northern Florida by a high area extending from Leon County eastward to Columbia County, where Oligocene rocks crop out. From a second outcrop area that extends southward from Citrus to Hillsborough Counties, Fla., Oligocene rocks slope into the South Florida basin, where the Oligocene top is more than 900 ft below sea level. The maximum measured depth to the top of the Oligocene is about 2,680 ft below sea level in well ALA-BAL-30 in southern Baldwin County, Ala. The maximum contoured depth is below 3,200 ft, to the southwest of this well. Although the top of the Oligocene is affected locally by erosion and karst topography, it is not as irregular as the top of upper Eocene strata.

The thickness of the Oligocene Series is shown on plate 11. Most of the contouring shown on this plate is based on well data. Where wells are scattered, the thickness of Oligocene rocks has been estimated by subtracting contours that represent the tops of upper Eocene and Oligocene rocks (pls. 8 and 10). Oligocene strata are generally less than 200 ft thick in the study area. Exceptions are southwestern Florida, where these rocks are more than 400 ft thick; southern Gulf and Franklin Counties, Fla., where they are more than 600 ft thick; and the southernmost part of Alabama, where they are more than 800 ft thick. These thick areas represent the South Florida basin, the Southwest Georgia embayment, and the northeastern rim of the Gulf Coast geosyncline, respectively. Throughout most of eastern Georgia and all of South Carolina, the thickness of the Oligocene Series only locally exceeds 100 ft and is generally 50 ft or less.

Suwannee Limestone and equivalent rocks

The name "Suwannee Limestone" was proposed by Cooke and Mansfield (1936, p. 71) for "yellowish limestone typically exposed along the Suwannee River in Florida, from Ellaville...almost to White Springs...." They considered these beds to be of Oligocene (Vicksburgian) age rather than Miocene as previous investigators had postulated. Cores and well cuttings examined during this study show that the Suwannee usually consists of two rock types: (1) cream to tan, crystalline, highly vuggy limestone containing prominent gastropod and pelecypod casts and molds and (2) white to cream, finely pelletal limestone containing small foraminifers and pellets of micrite bound by a micritic to finely crystalline limestone matrix. Although these two rock types are complexly interbedded in places, the pelecypod cast-and-mold limestone is more characteristic of the upper part of the Suwannee and is the lithology most representative of the entire formation in most of Georgia and eastern panhandle Florida. The micritic pelletal limestone that is characteristic of the lower part of the Suwannee is locally

found higher in the formation in southwestern Florida. Because the Suwannee, like the Ocala, cannot be divided everywhere, the two facies have not been delineated in this report.

The upper part of the Suwannee has been locally silicified, and this chert-rich horizon was named the Flint River Formation in Georgia. These silicified beds are rarely found in the subsurface and appear to merely represent local diagenetic conditions rather than a widespread mappable variation within the Suwannee. The term Flint River is accordingly not considered to be a valid formational name in this report.

The upper part of the Suwannee in the Georgia subsurface commonly consists of medium to coarsely crystalline, light-brown to honey-colored, saccharoidal, vuggy dolomite. The erosional remnants of Suwannee preserved as outliers several miles distant from the main bodies of Oligocene rocks (pl. 10) and consisting of either limestone or dolomite show that marine Oligocene strata once covered the entire study area. Locally, the cast-and-mold facies of the Suwannee contains fine-grained sand. Very locally, the micritic pelletal facies contains trace amounts of fine- to medium-grained, light- to dark-brown phosphate. In outcrop, the Suwannee locally weathers to a nodular, rubbly surface owing to the removal of layers, lenses, and stringers of soft argillaceous limestone.

The Suwannee grades northward in northeastern Georgia and South Carolina into part of the Cooper Formation by the addition of clay and sand and the loss of limestone. Westward, across panhandle Florida and southern Alabama, the Suwannee appears to grade into the lower part of the Bucatunna Formation. In that area, the Suwannee consists of tan limestone, dolomitic limestone, and light-colored calcareous clay. Some of these beds were called "Byram" or "Glendon" by early workers (Cooke and Mossum, 1929; Cooke, 1945) primarily on the basis of their stratigraphic position. Some faunal aspects of the Suwannee in Florida are Chickasawhayan (late Oligocene); others are Vicksburgian (early Oligocene). The unit is thus interpreted in this report as spanning both ages (pl. 2). The Suwannee in Georgia is thought to be late Oligocene (Huddlestun, 1981).

Microfauna considered characteristic of the Suwannee include the larger Foraminifera *Lepidocyclina leonensis* Cole and *L. parvula* Cole as well as the small Foraminifera *Pararotalia byramensis* Cushman and *P. mexicana mecatepecensis* Nutall, which are closely related. Although the genus *Miogypsina* ranges into younger strata in the central Gulf Coast, it does not occur above the top of the Suwannee in the study area. The larger Foraminifera *Discorinopsis gunteri* Cole, *Dictyoconus cookei* (Moberg), and *Coscinolina floridana* Cole are commonly found in the Suwannee, but these three species are also found lower in the section in the middle Eocene Avon Park Formation. Some authors think that these species have been reworked from the Avon Park into the Suwannee. Others think that they are merely long-ranging species that are "facies seekers." That is, their reappearance in the Suwannee means nothing more than the reestablishment of environmental conditions like those in which the Avon Park was deposited. Most individuals of these three species from the Suwannee examined during this study appeared fresh and unaltered, and the species are widespread throughout the cast-and-mold facies of the formation. In addition, there is no apparent Avon Park source from which these fossils could have been reworked. The isolated patches of Avon Park that are exposed through a cover of upper Eocene sediments (pl. 8) are too small and too scattered to provide a source from which these widely distributed Foraminifera could have been reworked into the Suwannee. This author therefore believes that these are long-ranging species indigenous to the Suwannee Limestone.

Bumpnose, Red Bluff, and Forest Hill Formations

In panhandle Florida, the Oligocene Series thickens considerably (pl. 11) and becomes increasingly clastic westward. In addition, some carbonate units that are older than the Suwannee are present at the base of the Oligocene (pl. 2). One such unit is the Bumpnose Formation, a name applied by Moore (1955) to a soft, white, somewhat glauconitic, highly fossiliferous (pelecypod and gastropod casts and molds and bryozoan and foraminiferal remains) limestone that crops out in central Jackson County, Fla. Moore thought that the Bumpnose represented the uppermost part of the late Eocene but recognized that many of its faunal elements were Oligocene. Subsequent work by Hazel and others (1980) confirmed the findings of MacNeil (1944) and Cooke (quoted by Moore, 1955, p. 38) that the beds that Moore called Bumpnose correlate with the Red Bluff Formation of Alabama of known Oligocene age. The Bumpnose in its type area is very likely a transitional unit between the late Eocene and early Oligocene. The Bumpnose Formation, however, is placed in the Oligocene in this report because carbonate rocks in western Alabama that are in the same stratigraphic position as the Bumpnose and that can be shown to correlate with it are of Oligocene age (Hazel and others, 1980).

The Bumpnose grades northwestward into the Red Bluff Formation, which is mostly dark-gray to brown, fossiliferous, glauconitic clay that contains some iron-

rich beds and siderite concretions, and local beds of glauconitic, sandy, fossiliferous limestone. The Red Bluff in turn grades westward into the Forest Hill Formation, a dark-colored silt, sand, and clay sequence that is highly lignitic near its top and base. Gulfward, the Bumpnose merges with the basal part of a thick sequence, unnamed at present, of interbedded pelletal limestone, micritic limestone, and tan, finely crystalline dolomite. To the southwest across the Florida panhandle, the Bumpnose pinches out in western Bay County, Fla. The Red Bluff and Forest Hill Formations are recognizable in the subsurface only a short distance downdip of their outcrop.

Mint Spring and Marianna Formations

The Marianna Formation is a soft, cream to white, highly fossiliferous (mostly large foraminifers), glauconitic limestone that is argillaceous in places. The amount of clay in the Marianna increases northwestward across southern Alabama as the Marianna grades into the Mint Spring Formation, a thin, fossiliferous, glauconitic sand or clayey sand that represents the base of the Vicksburg Group in western Alabama (Hazel and others, 1980). Gulfward from its type area in central Jackson County, Fla., the Marianna becomes part of a thick unnamed sequence of Oligocene limestone and dolomite beds. Like the Bumpnose, the Marianna pinches out to the southwest in western Bay County, Fla. The Mint Spring is not recognizable in the subsurface.

Glendon Formation

The Glendon Formation is a thin, fossiliferous, cream-colored limestone that occurs in the updip Oligocene of western Alabama. The Glendon is not recognizable in the subsurface in downdip areas of southern Alabama and panhandle Florida and is not thought to crop out in Florida. The micritic, pelletal, lower part of the outcropping Suwannee Limestone at its type locality was once thought to be equivalent to either the Glendon (Cooke and Mossum, 1929) or the Byram (Cooke, 1945). This report considers these beds to be part of the Suwannee.

Byram Formation

The Byram Formation in its outcrop area in western Alabama consists of light-colored, sandy, glauconitic, calcareous clay and some beds of sandy, white, fossiliferous limestone. The Byram is thin in outcrop and appears to merge with the Bucatunna Formation in the shallow subsurface by loss of limestone and increase of clay. In some publications, the terms Glendon and Byram appear to have been used somewhat interchangeably.

Bucatunna Formation

To the west of eastern Walton County and western Bay County, Fla., the basal unit of the subsurface Oligocene is a massive, light- to medium-gray, calcareous, fossiliferous clay containing trace amounts of fine sand. This unit, called the Bucatunna Formation, has a distinctive low-resistivity electric log pattern and constitutes one of the most easily recognizable stratigraphic markers in westernmost Florida and southern Alabama. Updip, the Bucatunna is less marine and consists of dark-colored carbonaceous silt, bentonitic clay and thin interbeds of yellow sand. The Bucatunna forms an excellent confining bed, separating permeable limestones of late Eocene age (Ocala) from late Oligocene limestone strata that are also highly permeable. The Bucatunna merges updip with more sandy or calcareous Oligocene beds and passes by facies change eastward into an unnamed thick sequence of limestone and dolomite beds of Oligocene age in eastern panhandle Florida.

Chickasawhay Formation

The uppermost part of the Oligocene Series in southern Alabama and much of panhandle Florida consists of white, micritic to pelletal, hard to semi-indurated, fossiliferous limestone and thin to thick beds of light- to dark-brown, fine to medium crystalline, vuggy dolomite. This unit is thought to be equivalent to the outcropping Chickasawhay Formation of western Alabama. The Chickasawhay in outcrop consists of bluish-gray, soft, glauconitic, calcareous clay and some beds of white fossiliferous limestone. The Chickasawhay can be distinguished in the subsurface as far east as central Bay County, Fla., where it grades into unnamed interbedded Oligocene limestone and dolomite that in turn thin and grade northward and eastward into the upper part of the Suwannee Limestone.

The Paynes Hammock Formation, a thin, calcareous, fossiliferous sand and clay sequence that overlies the Chickasawhay, cannot be distinguished from the Chickasawhay in the subsurface, and the two are thus not separated in this report.

In most of the subsurface of the western third of the study area, Oligocene strata can be divided into the basal Bucatunna Formation and the upper Chickasa-

whay Formation. Fauna considered to characterize these two units include the Foraminifera *Pulvinulina mariannensis* Cushman, *Robulus vicksburgensis* (Cushman) Ellisor, *Palmula caelata* (Cushman) Israelsky, and *Globigerina selli* (Borsetti). The ostracode *Aurila kniffeni* (Howe and Law) is also considered characteristic of these strata.

Cooper Formation (Ashley Member)

The uppermost part of the Cooper Formation, called the Ashley Member by Ward and others (1979), is of Oligocene age, in contrast to the late Eocene age of the lower two members of the Cooper. The Ashley Member consists of brown to tan, soft, calcareous, clayey sand that usually contains much phosphate and glauconite and carries a rich microfauna. The thickness of the member is highly variable. To the south and southeast, the Ashley Member grades into the Suwannee Limestone by the addition of impure limestone beds and the loss of clastic strata. The microfauna of the Cooper were not examined in enough detail during this study to determine which species are characteristic of any of the formation's members, including the Ashley. However, the foraminifer *Pararotalia mexicana mecatepcensis* Nutall was identified from the upper part of the Cooper in several wells in northeastern Georgia.

Chandler Bridge Formation

The Chandler Bridge Formation (Sanders and others, 1982) is a thin sequence of clayey phosphatic sand beds that unconformably overlies the Ashley Member of the Cooper Formation. Chandler Bridge beds occur locally and appear to be preserved only in low areas on the Ashley surface. The Chandler Bridge contains no microfauna and is dated Oligocene on the basis of its stratigraphic position and the primitive aspect of its cetacean fauna, which somewhat resembles forms found in the upper Oligocene of Europe.

Depositional environments

The Suwannee Limestone and the equivalent thick sequence of unnamed interbedded limestone and dolomite in eastern panhandle Florida were deposited in a carbonate bank environment. The part of the Cooper Formation that is of Oligocene age (Ashley Member) and the Chandler Bridge Formation that overlies it were laid down in a marginal marine environment. All of the Oligocene units in Alabama and those in updip areas of panhandle Florida were deposited in shallow marine to restricted marine (lagoonal or estuarine) environments. The formations that are mostly limestones (Bumpnose, Marianna, and Glendon) formed in shallow, warm, open marine waters. Those units that are highly argillaceous and glauconitic (Red Bluff, Mint Spring, Byram, and Chickasawhay) are estuarine to lagoonal for the most part but may grade into shallow shelf, open marine deposits downdip. The dark-colored clays that are part of the Forest Hill and the updip portion of the Bucatunna are mostly lagoonal but in places may represent deltaic conditions. The Bucatunna and Forest Hill represent local regressive phases of the generally transgressive Oligocene sea.

MIOCENE SERIES

Rocks of Miocene age underlie most of the study area except for a wide band in northwestern peninsular Florida, where they have largely been removed by erosion. These strata are mostly clastic, with the exception of (1) sandy limestone that comprises the Tampa Formation and its equivalents and (2) dolomite beds that commonly make up the lower part of the Hawthorn Formation. Miocene rocks crop out over more of the study area than any other Tertiary unit and are highly dissected in outcrop and shallow subcrop locales. The paleogeography of the eastern Gulf Coast was very different in Miocene time than it had been before. The carbonate bank environment that characterized peninsular Florida and adjacent areas during most of Tertiary time was covered during the Miocene by an influx of clastic sediments. Chemical conditions in parts of the Miocene ocean were also quite different and resulted in the widespread deposition of phosphatic and siliceous sediments, especially during middle Miocene time.

The extent and the configuration of the surface of the Miocene Series is shown on plate 12, along with the area where these rocks crop out. Over more than half of their extent, Miocene rocks are at or above sea level. The contour interval used on plate 12 is smaller than that used on maps of the structural surfaces of older units to better portray the irregular topography developed on the top of the Miocene. The rough surface of the unit and the numerous small outliers preserved as erosional remnants apart from the main body of Miocene rocks show that the Miocene surface has been deeply eroded. At a few scattered places within the main body of Miocene rocks, older units are exposed where the Miocene has locally been completely eroded through.

In outcrop areas in Alabama and Georgia, Miocene rocks are found at altitudes of more than 300 ft above

sea level. In south-central peninsular Florida, the Miocene top locally is at an altitude of more than 150 ft above sea level. The maximum measured depth to the top of the Miocene is about 1,360 ft below sea level in well ALA-BAL-30 in southern Baldwin County, Ala., and the maximum contoured depth of the unit is below 1,700 ft to the southwest of this well. Over much of south Florida, the Miocene top is 100 to 200 ft below sea level. Locally, along small faults in extreme southeastern Florida, the top of the unit has been dropped as much as 250 ft on the downthrown side of the faults. The only major structural features shown on plate 12 are a negative area in the southwestern tip of Florida that represents a part of the South Florida basin, and a steep gulfward slope of the Miocene top in southern Alabama produced by subsidence of the Gulf Coast geosyncline.

The thickness of the Miocene Series is shown on plate 13, as are those areas where the Tampa Limestone and its equivalents comprise part of the Miocene. The contours on this map are based primarily on well data. Certain features shown on this map, such as the small fault extending from Martin County to St. Lucie County in southeastern Florida, are taken from published sources. In areas of sparse control, the well-point data have been supplemented by subtracting contoured surfaces of the Miocene and Oligocene. Where Oligocene rocks are absent, the difference in altitude between the Miocene and late Eocene tops was used as a thickness approximation. Miocene strata thicken from a featheredge where they crop out to a thickness of more than 800 ft in southern Florida, more than 500 ft in southeastern Georgia, and more than 1,400 ft in southern Alabama. In a wide area across north-central peninsular Florida, Miocene rocks are very thin on the Atlantic side and absent to patchy on the Gulf side. This area of thinning generally coincides with an area where Oligocene rocks have been stripped (pl. 10) and where upper Eocene rocks are thin (pl. 9). The many local variations in the thickness of the Miocene shown on plate 13 are due to extensive erosion of the unit.

Although the Miocene rocks of the Southeastern United States have been studied in detail for many years, they remain poorly understood. This lack of understanding is due in part to the complexity of facies change within the rocks. For example, in western Florida, detailed work on somewhat scattered exposures of highly variable, shallow marine Miocene beds has resulted in a proliferation of "formations" whose extent and exact stratigraphic relations are poorly defined. Certain economic aspects of the Miocene, such as phosphorites and high-magnesium clays, have been closely scrutinized, but an economic study is likely to be of either local range or narrow focus. It is beyond the scope of this study to address the many problems of Miocene stratigraphy; therefore, the stratigraphic breakdown of the Miocene used herein is a general one (pl. 2). Greater detail on Miocene stratigraphy and various Miocene problems is presented in a collection of papers edited by Scott and Upchurch (1982).

The entire Miocene Series was mapped together as a single unit during this study. Microfauna that are considered characteristic of the undifferentiated Miocene in the study area include the Foraminifera *Amphistegina chipolensis* Cushman and Ponton, *A. lessoni* d'Orbigny, *Bolivina floridana* Cushman, *B. marginata multicostata* Cushman, *Elphidium chipolensis* (Cushman), and *Sorites sp.* Ostracoda considered characteristic of the Miocene include *Aurila conradi* (Howe and McGuirt) and *Hemicythere amygdula* Stephenson.

Tampa Limestone

The basal part of the Miocene Series in part of west-central peninsular Florida and much of the central and eastern parts of the Florida panhandle consists of the Tampa Limestone. As it is used in this report, the Tampa is a white to light-gray, sandy, hard to soft, locally clayey, fossiliferous (pelecypod and gastropod casts and molds) limestone that contains phosphate and chert in places. The phosphate content of the Tampa is low, however, in comparion with that of the overlying Hawthorn Formation. The mollusk remains in the Tampa vary from trace amounts up to 90 percent of the rock. Except for the sand and phosphate that it contains, the Tampa closely resembles the Suwannee Limestone. Some confusion exists in the literature as to the distinction between these formations, owing in part to the fact the Tampa-Suwannee contact is gradational in the type area of the Tampa (King and Wright, 1979). A difference of opinion also exists concerning the age of the Tampa. Certain mollusks from the unit are also found in the Paynes Hammock Formation of eastern Mississippi, once thought to be of early Miocene age but now known to be part of the Oligocene (Poag, 1972). Foraminifera from the Tampa, however, indicate that the formation is of early Miocene age, and the formation is placed in the early Miocene in this report.

From its type area in and around Tampa Bay, the Tampa Limestone grades southward into white, hard to semi-indurated, finely crystalline to micritic limestone that contains traces of sand, phosphate and scattered pelecypod casts and molds at irregular intervals. The basal part of this fine-textured limestone sequence consists largely of finely pelletal, micritic

limestone. To the east and south, all these limestones become silty, clayey, and dolomitic and appear to grade into the lower part of the Hawthorn Formation.

The light-gray, sandy, pelecypod- and gastropod-rich lower Miocene limestone in the eastern and central parts of the Florida panhandle has been called the Tampa Limestone by some workers and the St. Marks Formation by others. This author could not distinguish between the Tampa and the St. Marks either in outcrop or in well cuttings, and all fossiliferous lower Miocene limestones in the study area are therefore called Tampa Limestone in this report. The Tampa in the Florida panhandle appears to pinch out against the Hawthorn Formation where it is overlapped by the latter unit. Marsh (1966) recognized that some limestones in the southern parts of Escambia and Santa Rosa Counties in extreme western Florida contain an early Miocene fauna, but he was unable to separate these strata from underlying limestone beds of the Chickasawhay Formation (Oligocene). This author agrees that a thin sequence of limestone is present near the Gulf Coast in these counties but, like Marsh, cannot consistently differentiate the Oligocene and early Miocene there. The thin carbonate sequence is thus mapped as part of the Oligocene in this report.

The Tampa Formation does not extend into Georgia. The beds that Counts and Donsky (1963) and Herrick and Vorhis (1963) called Tampa are in reality part of the basal Hawthorn, which consists largely of dolomite and dolomitic limestone.

The Catahoula Sandstone, a yellowish-gray sand and sandy clay unit that occurs locally in outcrop and in the shallow subsurface in Alabama, is thought to be a lower Miocene unit and therefore time equivalent to the Tampa. The two formations, however, are not connected. The Catahoula appears to grade into the lower part of the Hawthorn Formation. The Edisto Formation of South Carolina, a yellow-brown, sandy, fossiliferous limestone that occurs as erosional remnants on the top of the Cooper Formation, is also of early Miocene age but, like the Catahoula, is not connected to the Tampa Limestone.

Microfauna identified from the Tampa during this study include the Foraminifera *Amphistegina chipolensis* Cushman and Ponton, *Elphidium chipolensis* (Cushman), and *Sorites* sp. These species are not restricted to the Tampa, however, and are commonly found also in younger Miocene units.

Hawthorn Formation

The Hawthorn Formation is the most widespread and the thickest Miocene unit in the Southeastern United States. East of longitude 85° W, the Hawthorn constitutes most of the entire thickness of the Miocene strata shown on plate 13. The Hawthorn is a complexly interbedded, highly variable sequence that consists mostly of clay, silt, and sand beds, all of which contain scarce to abundant phosphate. Phosphatic dolomite or dolomitic limestone beds are common in the lower part of the formation. The argillaceous beds of the Hawthorn are usually green but locally are cream or gray. Hawthorn sands are light to dark brown where they are highly phosphatic and light green to gray where they carry only trace amounts of phosphate. The dolomite and limestone beds of the Hawthorn are most commonly brown but locally are cream to white. Most of the phosphate that occurs throughout the Hawthorn is fine to medium sand sized, but beds of pebble-sized phosphate are by no means rare, especially in the upper third of the formation.

Locally, the Hawthorn can be roughly divided (Carr and Alverson, 1959; Miller and others, 1978; Scott and Upchurch, 1982). Although the number of zones and their exact lithology vary greatly from place to place, the Hawthorn generally consists of a basal calcareous unit, a middle clastic unit, and an upper unit that is a highly variable mixture of clastic and carbonate rocks. The middle and upper parts of the Hawthorn everywhere contain more phosphate than the lower calcareous unit. Hawthorn phosphorites are mined over a large area in central Florida and are locally exploited in Hamilton County in northern Florida. Although there is some disagreement about the exact environment of deposition and mechanism of concentration of the phosphate minerals in the Hawthorn, the consensus is that the phosphate was deposited from upwelling, cold marine waters (Riggs, 1979; Miller, 1982a).

There is much local variation of rock types within the Hawthorn. Some Hawthorn clay beds contain abundant diatom remains (Miller, 1978). Palygorskite (attapulgite), a magnesium-rich clay that is useful because of its absorptive properties, is mined from the upper part of the Hawthorn in Gadsden County, Fla., and Decatur County, Ga. (Weaver and Beck, 1977). In southwestern Florida, there are thick sequences of light-gray silty to argillaceous limestone in the upper and lower thirds of the formation. In Seminole and Orange Counties, Fla., the Hawthorn is very thin and consists of beds of shell material bound together by light-gray calcareous clay. Southeast of Tampa, Fla., the uppermost part of the Hawthorn consists of brown, orange, and red clayey, slightly phosphatic sand. In northeastern Georgia, Hawthorn beds consist mostly of green silt and clay and interbedded white limestone and fine- to coarse-grained sand.

Because of its heterogeneity and the predominantly fine textured nature of both the clastic and the carbonate beds within the Hawthorn, the entire formation

constitutes a low-permeability rock sequence. Where it is present, the Hawthorn Formation comprises most of the upper confining unit of the Floridan aquifer system.

The Hawthorn Formation is considered by most workers to be of middle Miocene age, and it is so regarded in this report. However, fauna are sparse within the Hawthorn, and the exact relations between this formation and the complex Miocene section of panhandle Florida are unclear at present. Parts of the Hawthorn may be as old as early Miocene or as young as late Miocene. Most of the unit, however, appears to be of middle Miocene age.

Alum Bluff Group

West of longitude 85° W, or approximately at the Apalachicola River in eastern panhandle Florida, the Hawthorn Formation passes by facies change into the lower part of a thinly bedded, complex, finely to coarsely clastic, often highly shelly sequence of strata called the Alum Bluff Group (pl. 2). Several formations have been identified within this group, chiefly on the basis of work done in outcrop areas and in the shallow subsurface. For the most part, these formations are thin and of limited areal extent, and are in many cases not well defined. More detail on the Miocene of panhandle Florida is presented in reports by Puri (1953a), Puri and Vernon (1964) and in a collection of papers edited by Scott and Upchurch (1982).

The Alum Bluff Group as used in this report refers to a sequence of gray to green clay and medium- to coarse-grained sand beds that locally contain much carbonized plant material or mollusk shells. Beds of middle and late Miocene age have been reported from the Alum Bluff Group, but no age separation within the group has been made in this study. Alum Bluff beds grade westward into coarse gravelly sands and thin clay interbeds in westernmost Florida and southwestern Alabama. Alum Bluff Group equivalents in southern Alabama are an undifferentiated sequence of gray clays and fine- to medium-grained sands. Local, patchy erosional remnants of upper Miocene beds that occur at scattered places in parts of peninsular Florida are equivalent to the upper part of the Alum Bluff Group but are undifferentiated in this report.

Depositional environments

The mollusk-rich, cast-and-mold limestone of the Tampa represents a remnant of the carbonate bank environment that characterized the Florida peninsula throughout most of Tertiary time. The Tampa was deposited in warm, shallow, clear, open marine waters in a basin that received little or no clastic supply.

The Hawthorn Formation was deposited under conditions quite different from those that existed in the early Miocene. Hawthorn sediments were laid down in shallow to moderately deep (inner to middle shelf) marine waters in a basin that received copious amounts of clastic material. The highly phosphatic and siliceous (diatom rich) beds of the Hawthorn, as well as some of the microfauna recovered from the formation, show that the waters in the Hawthorn sea were colder than those in which older Cenozoic units were deposited. The considerable local relief on the Hawthorn sea floor (Miller, 1982a) was a factor in the deposition and concentration of some of the Hawthorn phosphorites.

The Alum Bluff Group was deposited in shallow, warm to temperate waters, mostly in a marginal marine environment. Some of the gravelly sands that are part of the Alum Bluff Group in westernmost Florida may be of fluvial origin.

TERTIARY AND QUATERNARY SYSTEM: POST-MIOCENE ROCKS

GENERAL

All beds in the study area that are younger than Miocene are grouped together in this report and mapped as a single unit. Post-Miocene strata can generally be divided into a basal sequence of marginal to shallow marine beds overlain by a series of sandy marine terrace deposits that are in turn capped by a thin layer of fluvial sand and (or) residuum. The basal beds having a marine aspect are mostly of Pliocene age, the terrace deposits were laid down during the Pleistocene, and the fluvial and residual materials are of Holocene age (pl. 2). There are two major exceptions to this general post-Miocene sequence. In southern Florida, practically all post-Miocene strata are of shallow or marginal marine origin and comprise a complex and highly variable sequence of thin formations whose relations are best known along the southeastern coast. In southwestern Alabama and the westernmost part of the Florida panhandle, post-Miocene rocks are mostly a thick sequence of coarse-grained, fluvial, gravelly sands that locally contain interbedded clays, mostly near the base of the sand sequence.

The top of post-Miocene rocks has not been mapped because the surface of the unit obviously is the same as the present-day topographic surface in the study area and the configuration of this surface is available from other published sources. The general thickness of

post-Miocene rocks is shown on plate 14. This map has been contoured on the basis of well data alone, in contrast with the thickness maps of the older units discussed in this report. The purpose of plate 14 is to show the locations of the larger thickness variations in the post-Miocene unit rather than detailed changes. Over most of the study area, post-Miocene sediments are less than 100 ft thick and in many places form a surface veneer that is only 10 to 50 ft thick. In southwestern Alabama, thick Pliocene fluvial deposits make up most of the 1,400-ft-thick sequence of post-Miocene rocks found there.

PLIOCENE SERIES

Pliocene deposits in western panhandle Florida and in southwestern Alabama are assigned in this report to the Citronelle Formation. The Citronelle is a thick, mostly fluvial unit that consists mainly of medium to coarse sand containing many stringers of gravel and a few thin clay beds. There is much iron oxide in the formation, along with minor amounts of organic material. It is possible that the upper part of the Citronelle is Pleistocene in age (Marsh, 1966) but the entire formation is placed in the Pliocene in this report. The Citronelle thins to the north and east, and, if it is present outside southwestern Alabama and western Florida, it cannot be distinguished from younger terrace deposits.

Pliocene rocks in much of central Florida are represented by the Bone Valley Formation, a highly phosphatic sequence of sand and clay beds that locally contains a vertebrate fauna of Pliocene age. The extent and thickness of the Bone Valley are uncertain because the unit is difficult to distinguish from the underlying Hawthorn Formation in places. In southeastern Florida, the Tamiami Formation, a white to cream limestone that contains much sand in pockets and as admixed material, is of Pliocene age. The Tamiami and the Bone Valley are not connected. The Caloosahatchee Formation overlies the Tamiami in southern Florida. In scattered places in central and northern peninsular Florida, thin patches of shallow marine rocks are probably Caloosahatchee equivalents. The Caloosahatchee and its equivalents consist of a thin sequence of interbedded clay, calcareous clay, and sand that locally contains much broken shelly material. The upper part of the Caloosahatchee is of Pleistocene age (pl. 2).

The Raysor Formation of southwestern South Carolina is a bluish-gray, shelly, calcareous sand unit of Pliocene age that extends into northeastern Georgia. Beds now called Raysor were formerly included in the Duplin Formation of northeastern South Carolina, but Blackwelder and Ward (1979) showed that the Raysor is a separate unit. The Goose Creek Limestone (Weems and others, 1982) is a sandy, phosphatic, shelly limestone of Pliocene age that is found locally in South Carolina. The relation between the Goose Creek and the Raysor is not known at present (1984) since the two units have not been found in contact. In southeastern Georgia, the Charlton Formation, a dark brownish-green, soft, fossiliferous, locally micaceous to phosphatic clay, represents the Pliocene Series.

PLEISTOCENE SERIES

Over most of the study area, Pleistocene rocks consist of medium- to coarse-grained, tan, white, and brown sand that locally contains trace amounts of carbonaceous material and broken shell fragments. These sands underlie a series of poorly defined to well-defined terraces that are thought to have formed during the Pleistocene Epoch as seas rose and fell in response to glacial and interglacial episodes (MacNeil, 1950). There is little agreement on the number of these terraces, however, and it is possible that some of the higher ones represent pre-Pleistocene deposits (Healy, 1975). In this report, all the terrace materials are considered to be Pleistocene.

In southwestern South Carolina and northeastern Georgia, the sandy terrace deposits are locally underlain by red and yellow sands that contain thin beds of shell and stringers of phosphate. These strata are equivalent to the Waccamaw Formation of northeastern South Carolina. In southeastern Florida, Pleistocene strata consist of a series of thin and variable marine to marginal marine deposits whose relations are complex. Several highly permeable clastic and carbonate Pleistocene units, taken together, comprise most of the Biscayne aquifer, an important source of water in southeastern Florida. For purposes of this report, separate Pleistocene formations are not delineated in southern Florida. Detailed studies on the Pleistocene of southern Florida include reports by Parker and Cooke (1944), DuBar (1958), and Puri and Vernon (1964).

HOLOCENE SERIES

Holocene deposits in the study area include thin sand and gravel deposits that are mostly adjacent to present-day streams and dune, estuarine, and lagoonal sediments contiguous to the modern coast. Residuum developed from the weathering of older sediments and local windblown materials are also included in the Holocene. Holocene strata are not mapped separately in this report, nor are the different Holocene depositional environments delineated.

DEPOSITIONAL ENVIRONMENTS

Pliocene rocks in southeastern Florida (Tamiami and Caloosahatchee Formations) were deposited in shallow to marginal marine environments. The Bone Valley Formation of central Florida is mostly of fluvial origin and is comprised largely of material reworked from underlying Miocene rocks (Puri and Vernon, 1964). The Citronelle Formation of southern Alabama and westernmost Florida represents a thick sequence of fluvial beds. The Raysor and Charlton Formations of South Carolina and easternmost Georgia were deposited in lagoonal to estuarine conditions. The Goose Creek Limestone was laid down in a shallow marine (inner shelf) environment.

Pleistocene rocks throughout most of the study area represent a series of constructional sandy marine terraces deposited at the shoreline of a fluctuating Pleistocene sea. The Waccamaw Formation equivalents in South Carolina and the complex series of Pleistocene units in southeastern Florida represent marginal marine depositional conditions. All Holocene materials in the study area are either of fluvial origin or derived from the weathering of older rocks.

AQUIFERS AND CONFINING UNITS

GENERAL

The ground-water system beneath the study area generally consists of two major water-bearing units; a surficial aquifer and the Floridan aquifer system. In most places, a low-permeability sequence of rocks herein called the upper confining unit of the Floridan aquifer system separates the Floridan from the surficial aquifer. The Floridan is everywhere underlain by low-permeability rocks that are called the lower confining unit of the Floridan aquifer system in this report.

The surficial aquifer consists mostly of poorly consolidated to unconsolidated clastic rocks (except for southeastern Florida, where it is composed of limestone). Most of the water within the surficial aquifer occurs under unconfined conditions. The Floridan aquifer system's upper confining unit, which lies between the Floridan and the surficial aquifer in many places, consists mostly of low-permeability clastic rocks.

The Floridan aquifer system is a more or less vertically continuous sequence of generally highly permeable carbonate rocks whose degree of vertical hydraulic connection depends largely on the texture and mineralogy of the rocks that comprise the system. The high permeability is only rarely vertically continuous. Flowmeter data from scattered wells show that the aquifer system usually consists of several very highly permeable zones, which generally conform to bedding planes and which commonly are either solution riddled or fractured. These zones, which contribute most of the water to wells, are separated by rocks whose permeability ranges from only slightly less to considerably less than that of the high-yield zones. Because the aquifer system (and its upper and lower confining beds) is defined primarily on the basis of permeability, both the top and the base of the system as mapped in this report are composite surfaces that locally cross formation and age boundaries. Accordingly, the time- and rock-stratigraphic units that make up the aquifer system and its contiguous confining beds vary widely from place to place.

Over much of southern Florida, the aquifer system consists of several relatively thin, highly permeable zones isolated from one another by relatively thick sequences of low-permeability rocks. Differences in the hydraulic heads the several highly permeable zones and differences in the quality of the water that they contain show that the zones behave essentially as separate aquifers.

The Floridan aquifer system's lower confining unit consists of either low-permeability clastic rocks or evaporite deposits. The Floridan is everywhere underlain by these relatively impermeable strata, which separate the high-permeability carbonate rocks from older, deeper aquifers that are mostly of Cretaceous age.

SURFICIAL AQUIFER

A surficial aquifer containing water under mostly unconfined or water-table conditions is present throughout all of the study area except for those places where the Floridan aquifer system or its overlying confining bed is exposed at land surface. The surficial aquifer consists predominantly of sand, but gravel, sandy limestone, and limestone are important constituents in places. Where surficial deposits are thick, highly permeable, and extensively used as sources of ground water, they have been given aquifer names such as the Biscayne aquifer in southeastern Florida and the sand-and-gravel aquifer in westernmost panhandle Florida. Figure 6 shows the extent of the Biscayne and sand-and-gravel aquifers, which grade laterally into widespread but thin sands that are called simply a surficial aquifer.

The term surficial aquifer as used in this report refers to any permeable material (other than that which is part of the Floridan aquifer system) that is exposed at land surface and that contains water under mostly unconfined conditions. The surficial aquifer may be in direct hydraulic contact with the Floridan or

be separated from it by confining beds. Rainfall easily infiltrates the permeable surficial materials and, after percolating downward to the water table, moves either laterally to points where it is discharged into surface streams or vertically downward to recharge either the Floridan or local intermediate aquifers, if the water levels in these deeper aquifers are lower than those in the surficial aquifer. Such downward leakance may be rapid or slow, depending on the presence and character of intervening confining beds (low-permeability rocks) and the head differences between the surficial aquifer and deeper aquifers. Water levels within the surficial aquifer fluctuate widely and rapidly in response to rainfall and other natural stresses such as evapotranspiration or the stages of streams. The general configuration of the water-level surface (water table) of the surficial aquifer is a subdued replica of the configuration of land surface.

The surficial aquifer is important in simulating ground-water flow in the Floridan aquifer system because it serves as a "source-sink" bed for the Floridan. Where the head at the base of the surficial aquifer is higher than the potentiometric surface of the underlying Floridan, the surficial aquifer is the "source" of water that moves downward to recharge the Floridan. Where the potentiometric surface of the Floridan is higher than the head at the base of the surficial aquifer, flow is upward from the Floridan to the surficial

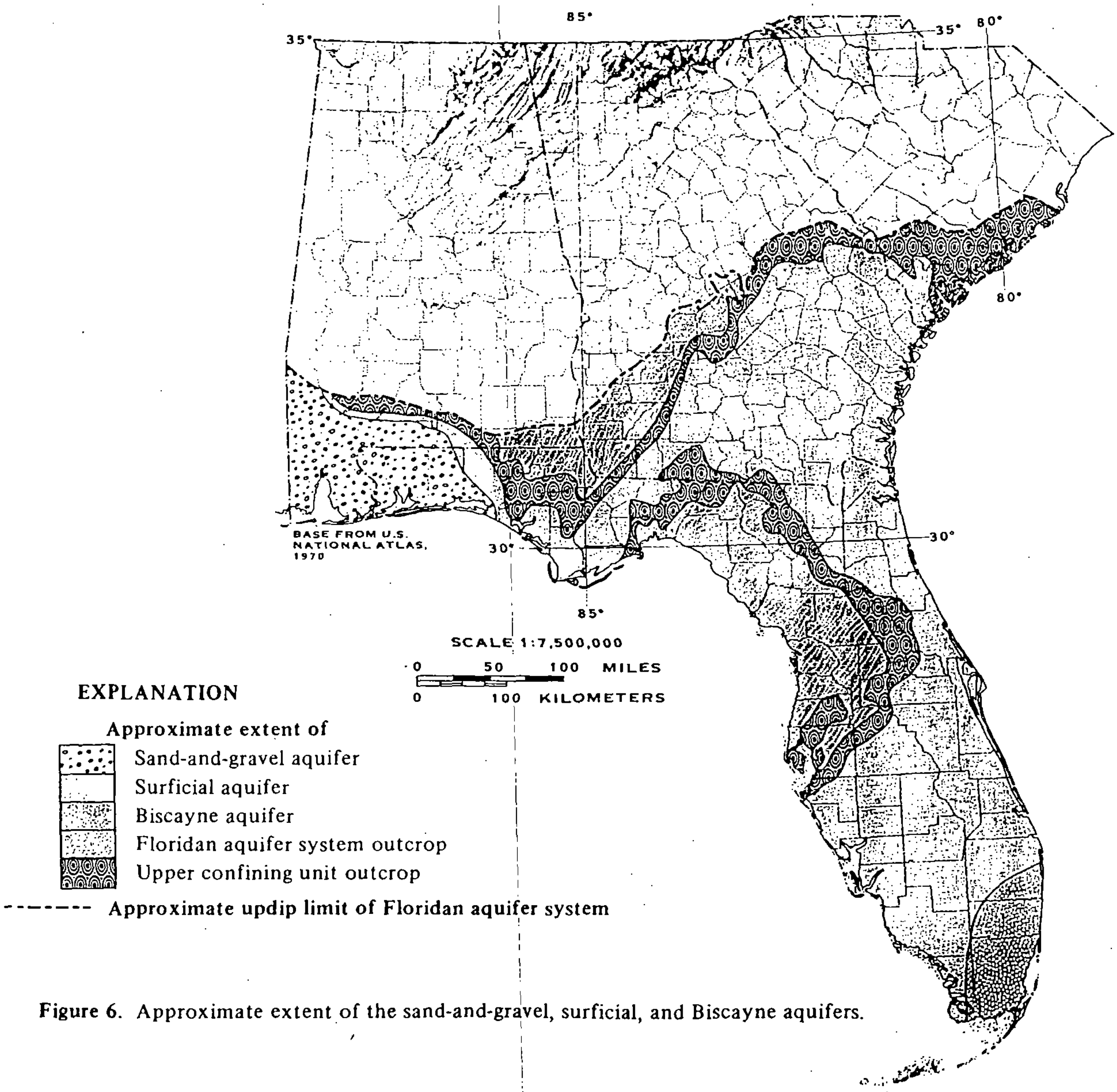


Figure 6. Approximate extent of the sand-and-gravel, surficial, and Biscayne aquifers.

aquifer. In such areas, the surficial aquifer is considered a hydraulic "sink." The thickness and lithologic character of the confining beds that separate the surficial aquifer from the Floridan aquifer system determine the degree of hydraulic interconnection between the two.

The surficial aquifer in the strict sense as mapped on figure 6 consists of all surficial strata containing water under unconfined conditions other than the Biscayne and sand-and-gravel aquifers. Given these restrictions, the surficial aquifer consists mostly of unconsolidated sand and shelly sand deposits that are predominantly of Holocene age but in places include deposits of Pleistocene and Pliocene age. For example, Pleistocene sands that are preserved as ancient beach and shoreline deposits, offshore bars, and the flows of marine terraces (Healy, 1975) are part of the surficial aquifer. Klein (1972) and Hyde (1975) included shell beds and sands of the Anastasia Formation (Pleistocene) and limestones of the Tamiami Formation (Pliocene) in southern Florida in a nonartesian aquifer that they termed the "shallow aquifer"—the equivalent of the surficial aquifer of this report. Callahan (1964) thought that the surficial "sand aquifer" in Georgia consisted of Pliocene to Holocene sands that reach a thickness of about 100 ft in southeastern Georgia. Klein (1972) recorded 130 ft of surficial aquifer in southwestern Florida. The maximum measured thickness of the surficial aquifer recorded during this study is 325 ft in well GA-COF-1 in Coffee County, Ga.

Because the sands designated surficial aquifer on figure 6 are mostly thin and discontinuous in places, water is produced from them primarily for domestic use. Where no other source of ground water exists and the surficial aquifer is sufficiently thick, the aquifer supplies water for industrial or municipal use. Highly permeable strata containing water under nonartesian conditions are the principal source of supply for large municipalities in two areas. These strata are the lateral equivalents of the surficial aquifer. In southeastern Florida, these highly permeable rocks are called the Biscayne aquifer (fig. 6); in extreme western panhandle Florida and south Alabama, they are called the sand-and-gravel aquifer.

The Biscayne aquifer is the source of supply for all municipal water systems in the Palm Beach-Miami area of Florida. Over 500 Mgal/d of water are currently pumped from the Biscayne (Klein and Hull, 1978). The Biscayne is a wedge-shaped body of highly permeable limestone, sandstone, and sand that thickens from a featheredge at its western boundary to more than 200 ft near the Atlantic coast in eastern Broward County (well FLA-BRO-1). The sand content of the aquifer is higher to the north and east; limestone and sandstone are more prominent to the south and west. Included in the Biscayne aquifer are several sand and limestone units of Pleistocene age, the Pliocene and Pleistocene Caloosahatchee Formation, and the upper part of the Pliocene Tamiami Formation (Franks, 1982). Permeability is highest in those areas where the aquifer is mostly limestone, partly because of the development of solution cavities in the limestone. In limestone-rich areas, the transmissivity of the Biscayne aquifer is greater than 1.6×10^6 ft^2/d, but decreases to about 5.4×10^4 ft^2/d where the aquifer is mostly sand (Klein and Hull, 1978). Because of its high permeability and because it is intensively used as a source of water, the Biscayne is subject to contamination by saltwater intrusion from the ocean and by infiltration from an extensive system of canals cut into it that are connected to the ocean. The Biscayne is everywhere separated from the Floridan aquifer system by a thick sequence of low-permeability argillaceous rocks that are mostly of Miocene age. More detailed discussions of the Biscayne aquifer have been given byParker and others (1955), Schroeder and others (1958), Klein and Hull (1978), and Franks (1982).

The sand-and-gravel aquifer (fig. 6) consists primarily of quartz sand that contains much gravel-sized quartz as disseminated particles and as layers. Geologic units included by Franks (1982) in the sand-and-gravel aquifer are, from oldest to youngest, (1) coarse clastics that are probably equivalent to part of the Alum Bluff Group of Miocene age, (2) the Pliocene Citronelle Formation, (3) undifferentiated Pleistocene terrace deposits, and (4) Holocene alluvium. The aquifer thickens southward and westward from a featheredge in southern Alabama and in Walton County, Fla., to a maximum measured thickness of about 1,400 ft in well ALA-MOB-17 in Mobile County, Ala. Locally, layers and lenses of clay within the aquifer form semiconfining beds and create confined conditions in the permeable materials that lie between clay beds. For the most part, however, water in the sand-and-gravel aquifer is unconfined. The aquifer is the primary source of ground water in western panhandle Florida and southwestern Alabama. In places near its updip limit, the sand-and-gravel aquifer is in direct hydraulic contact with the Floridan aquifer system. However, the two aquifers are for the most part separated by thick clay beds. The transmissivity of the sand-and-gravel aquifer is locally as high as about 2×10^4 ft^2/d (Musgrove and others, 1961). Detailed descriptions of the geology and hydrologic characteristics of the sand-and-gravel aquifer have been presented by Musgrove and others (1961), Barraclough and Marsh (1962), Marsh (1966), Trapp (1978), and Franks (1982).

UPPER CONFINING UNIT

Over much of the study area, the Floridan aquifer system is overlain by an upper confining unit that consists mostly of clastic rocks but locally contains much low-permeability limestone and dolomite in its lower parts. In places, the upper confining unit has been removed by erosion, and the Floridan either crops out or is covered by only a thin veneer of permeable sand that is part of the surficial aquifer. Because the lithology and thickness of the upper confining unit are highly variable, the unit retards the vertical movement of water between the surficial aquifer and the Floridan aquifer system in varying degrees. Where the upper confining unit is thick or where it contains much clay, leakance through the unit is much less than where it is thin or highly sandy. In these thick or clay-rich areas, therefore, water in the surficial aquifer moves mostly laterally and is discharged into surface-water bodies rather than moving downward through the upper confining unit (when the head differential is favorable) to recharge the Floridan aquifer system.

The upper confining unit may be breached locally by sinkholes and other openings that serve to connect the Floridan aquifer system directly with the surface. These sinkholes are for the most part found where the thickness of the upper confining unit is 100 ft or less. They appear to result from the collapse of a relatively thin cover of clastic materials into solution features developed in the underlying limestone of the Floridan aquifer system rather than from the solution of limestone beds within the upper confining unit itself. The upper confining unit is generally more sandy where it is less than 100 ft thick because these relatively thin areas represent upbasin depositional sites where coarser clastic rocks were laid down. Plate 25 shows the extent and thickness of the upper confining unit. The maximum measured thickness of the unit is about 1,890 ft in well ALA-BAL-30 in Baldwin County, Ala. The maximum contoured thickness is 1,900 ft. Plate 25 also shows areas where water in the Floridan aquifer system occurs under unconfined, thinly confined (thickness of upper confining unit between 0 and 100 ft), and confined conditions.

The upper confining unit includes all beds of late and middle Miocene age, where such beds are present. Locally, low-permeability beds of post-Miocene age are part of the upper confining unit. Over most of the study area, middle Miocene and younger strata consist of complexly interbedded, locally highly phosphatic sand, clay, and sandy clay beds, all of which are of low permeability in comparison with the underlying limestone of the Floridan aquifer system. Locally, low-permeability carbonate rocks that are part of the lower Miocene Tampa Limestone or of the Oligocene Suwannee Limestone are included in the upper confining unit. Very locally, in the West Palm Beach, Fla., area, the uppermost beds of rocks of late Eocene age are of low permeability and are included in the upper confining unit.

Parker and others (1955) and Stringfield (1966) included basal beds of the Hawthorn Formation in their Floridan and principal artesian aquifers where those beds are permeable. In a few isolated cases (for example, in Brevard County, Fla.), the lowermost Hawthorn strata are indeed somewhat permeable, but their permeability is considerably less than that of the underlying Floridan aquifer system, as Parker and others (1955, p. 84) recognized. Locally, in parts of southwestern Florida (Sutcliffe, 1975; Boggess and O'Donnell, 1982) and west-central peninsular Florida (Ryder, 1982), permeable zones within the Hawthorn Formation are an important source of ground water over a one- or two-county area. Although some of these permeable zones are limestones, their transmissivity is at least an order of magnitude less than that of the Floridan aquifer system, and they are separated from the main body of permeable limestone (Floridan) by thick confining beds. Because of their limited areal extent, relatively low permeability, and vertical separation from the Floridan aquifer system practically everywhere, water-bearing Hawthorn limestones are excluded from the Floridan in this report.

Where the limestone and dolomite of the Floridan crop out, a clayey residuum may form over the carbonate rocks as a result of chemical weathering that dissolves the carbonate minerals and concentrates trace amounts of clay that are in them. Such residumm is particularly well developed in the Dougherty Plain area of southwestern Georgia (Hayes and others, 1983). Although this residuum is a low-permeability material and may very locally form a semiconfining layer above the limestone, it is usually thin and laterally discontinuous. Accordingly, the clayey residuum is not included in this report as part of the upper confining unit of the Floridan aquifer system.

Because the rocks that comprise the upper confining unit vary greatly in lithology, are complexly interbedded, and for the most part are of low permeability, little is known about their hydraulic characteristics. Where clay beds are found in the Hawthorn Formation, they are usually very effective confining beds. Vertical hydraulic conductivity values for Hawthorn clays, as established from core analysis and from aquifer tests, range from 1.5×10^{-2} ft/d (Hayes, 1979) to 7.8×10^{-7} ft/d (Miller and others, 1978). Where sandy beds of the Hawthorn comprise a local aquifer, transmissivity values for the sand range as high as

about 13,000 ft^2/d (Ryder, 1982). Hawthorn limestone beds that are local aquifers yield up to 750 gal/min (Boggess, 1974).

FLORIDAN AQUIFER SYSTEM

GENERAL

The Floridan aquifer system is a thick sequence of carbonate rocks generally referred to in the literature as the "Floridan aquifer" in Florida and the "principal artesian aquifer" in Georgia, Alabama, and South Carolina. As defined in this report, the Floridan aquifer system encompasses more of the geologic section and extends over a wider geographic area than either the Floridan or the principal artesian aquifer, as those aquifers have been described in the literature. Figure 7 shows the geologic formations in Florida and southeastern Georgia that were called "principal artesian formations" by Stringfield (1936), those that were included in the "Floridan aquifer" as defined by Parker and others (1955), and those placed in the "principal artesian aquifer" as defined by Stringfield (1966). Subsequent deep drilling and hydraulic testing have shown that highly permeable carbonate rocks extend to deeper stratigraphic horizons than those included in either the "Floridan" or "principal artesian" aquifers as originally described. Accordingly, this author (cited by Franks, 1982) extended the base of the Floridan aquifer downward to include part of the upper Cedar Keys Limestone (fig. 7). Limestone and dolomite beds that commonly occur at the base of the Hawthorn Formation have been included as part of the "Floridan" or "principal artesian" aquifer in most previous reports. However, data collected for the present study show that, except very locally, there are no high-permeability carbonate rocks in the lower part of the Hawthorn Formation that are in direct hydraulic contact with the main body of the Floridan aquifer system.

The Hawthorn Formation was thus excluded from the aquifer system in a report by Miller (1982a) that was one of a series of several interim reports published during the present study. In these interim reports, the aquifer system was called the "Tertiary limestone aquifer system of the Southeastern United States." This cumbersome, albeit more accurate, terminology has subsequently been abandoned, and the aquifer system is referred to in this professional paper as the "Floridan aquifer system" (see Johnston and Bush, 1985 for a more detailed history of the terminology applied to the aquifer system).

The Floridan aquifer system is defined in this report

EPOCH		Stringfield (1936) Formation	Stringfield (1936) Aquifer	Parker and others (1955) Formation	Parker and others (1955) Aquifer	Stringfield (1966) Formation	Stringfield (1966) Aquifer	Miller, in Franks (1982) Formation	Miller, in Franks (1982) Aquifer	Miller (1982 a,c) Formation	Miller (1982 a,c) Aquifer system	This Report Formation	This Report Aquifer system
MIOCENE	Middle	Hawthorn Formation		Hawthorn Formation		Hawthorn Formation		Hawthorn Formation	Where Permeable	Hawthorn Formation		Hawthorn Formation	
MIOCENE	Early	Tampa Limestone	Principal artesian formations	Tampa Limestone	Where Permeable	Tampa Limestone	Principal artesian aquifer	Tampa Limestone	Where Permeable	Tampa Limestone	Where Permeable	Tampa Limestone	Where Permeable
OLIGOCENE		Oligocene Limestone	Principal artesian formations	Suwannee Limestone	Floridan aquifer	Suwannee Limestone	Principal artesian aquifer	Suwannee Limestone	Floridan aquifer	Suwannee Limestone	Tertiary limestone aquifer system	Suwannee Limestone	Floridan aquifer system
EOCENE	Late	Ocala Limestone	Principal artesian formations	Ocala Limestone	Floridan aquifer	Ocala Limestone	Principal artesian aquifer	Ocala Limestone	Floridan aquifer	Ocala Limestone	Tertiary limestone aquifer system	Ocala Limestone	Floridan aquifer system
EOCENE	Middle			Avon Park Limestone; Lake City Limestone	Floridan aquifer	Avon Park Limestone; Lake City Limestone	Principal artesian aquifer	Avon Park-Lake City Limestones	Floridan aquifer	Avon Park-Lake City Limestones	Tertiary limestone aquifer system	Avon Park Formation	Floridan aquifer system
EOCENE	Early					Oldsmar Limestone	Principal artesian aquifer	Oldsmar Limestone	Floridan aquifer	Oldsmar Limestone	Tertiary limestone aquifer system	Oldsmar Formation	Floridan aquifer system
PALEOCENE								Cedar Keys Limestone		Cedar Keys Limestone		Cedar Keys Formation	

Figure 7. Comparison of aquifer terminologies.

as a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of middle and late Tertiary age and hydraulically connected in varying degrees and whose permeability is, in general, an order to several orders of magnitude greater than that of those rocks that bound the system above and below. As plate 2 shows, the Floridan aquifer system includes units of late Paleocene to early Miocene age. Very locally, in the Brunswick, Ga., area, the entire Paleocene section plus a thick sequence of rocks of Late Cretaceous age are part of the aquifer system. In and just downdip of the area where the aquifer system crops out, the entire system consists of one vertically continuous permeable unit. Farther downdip, less permeable carbonate units of subregional extent separate the system into two aquifers, herein called the Upper and Lower Floridan aquifers (fig. 8). These less permeable units may be very leaky to virtually nonleaky, depending on the lithologic character of the rock comprising the unit. Because they lie at considerable depth, the hydrologic character and the importance of the subregional low-permeability units are known from only a few scattered deep test wells. Local low-permeability zones may occur within either the Upper or the Lower Floridan aquifer. In places (for example, southeastern Florida), low-permeability rocks account for slightly more than half of the rocks included in the aquifer system.

Even though the rocks that comprise the base of the Upper Floridan aquifer are not everywhere at the same altitude or geologic horizon or of the same rock type, the presence of a middle confining unit over about two-thirds of the study area has led to a conceptual model for the Floridan aquifer system that consists of two active permeable zones (the Upper and Lower Floridan aquifers) separated by a zone of low permeability (a middle confining unit). Because of this simplified layering scheme, it is necessary to greatly generalize the highly complex sequence of high- and low-permeability rocks that comprise the aquifer system. Local confining beds (see, for example, cross section E-E', pl. 21) are either disregarded because they are regionally unimportant or lumped with one of the major layers. The purpose of the conceptual model, and of the digital computer model derived from it and described by Bush and Johnston (1985) is to portray the major aspects of ground-water flow within the Floridan aquifer system. In like manner, the descrip-

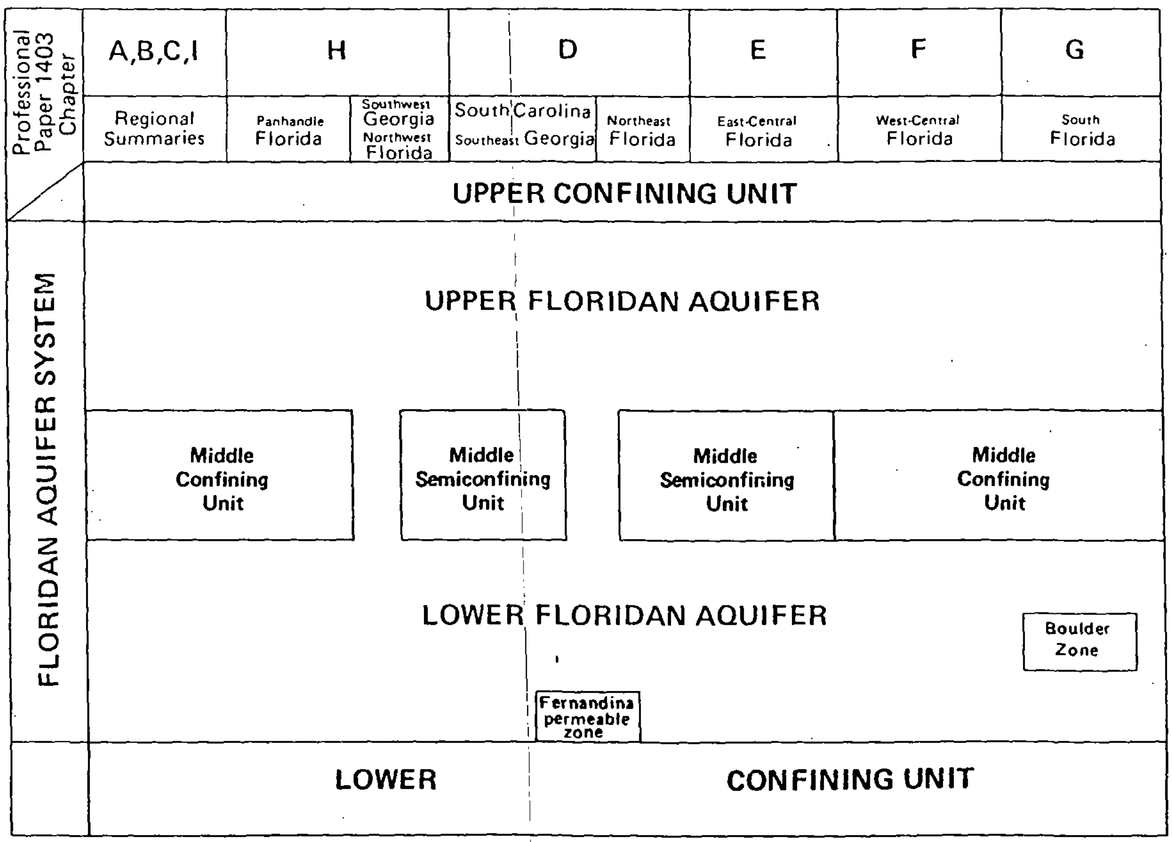


Figure 8. Aquifers and confining units of the Floridan aquifer system.

tion of the aquifer system's geohydrologic framework in this report is intended to show the principal variations in permeability within the aquifer system. In both cases, local anomalies that do not fit with overall (regional) conditions are ignored.

Regionally, the top of the Floridan aquifer system in most places lies at the top of rocks of Oligocene age (Suwannee Limestone) where these strata are preserved. Where Oligocene rocks are absent, the aquifer system's top is generally at the top of upper Eocene rocks (Ocala Limestone). Locally, in eastern panhandle Florida and in west-central peninsular Florida, rocks of early Miocene age (Tampa Limestone) are highly permeable and hydraulically connected to the aquifer system. In places, upper Eocene through lower Miocene rocks are either missing owing to erosion or nondeposition or of low permeability; at these places, rocks of middle Eocene age (Avon Park Formation) mark the top of the aquifer system. It is important to note that there are some places where the upper part of a given formation that comprises the top of the aquifer system consists of low-permeability rocks. At such places, the low-permeability beds are excluded from the aquifer system, and the top of the system is considered to be the top of the uppermost high-permeability carbonate rock. The top of the system, then, may lie within a stratigraphic unit rather than at its top. Because the permeability contrast between the aquifer system and its upper confining unit does not everywhere follow stratigraphic horizons, neither does the top of the aquifer system. Likewise, the top of the aquifer system may locally lie within a limestone unit if the upper part of the limestone consists of low-permeability rock and the lower part is highly permeable.

The time-stratigraphic units or parts of units that mark the top of the Floridan aquifer system at selected localities are shown in figure 9, as well as the time-rock units that comprise the Upper and Lower Floridan aquifers and the units that are considered to represent the aquifer system's base. Figure 9 shows a series of idealized chronostratigraphic columns compiled from well data at several locations in the study area, along with the permeability characteristics of each chronostratigraphic unit at each location. Examination of this figure shows that, in addition to the variations in the top and base of the aquifer system, the degree of complexity varies greatly within the system. Generally speaking (and as figure 9 shows), the aquifer system in most places can be divided into an Upper and Lower Floridan aquifer separated by less-permeable rock. In places, however, no middle confining unit exists (for example, the Baxley, Ga., and Gainesville, Fla., columns on fig. 9), and the aquifer system is highly permeable throughout its vertical extent. In other places, thick sequences of low-permeability rock occur at several levels within the aquifer system (for example, the Savannah, Ga., and West Palm Beach, Fla., areas in fig. 9), and the several discrete permeable zones of the system may be hydraulically separated.

Regionally, and in a fashion similar to the way in which the top is defined, the base of the aquifer system is defined as the level below which there is no high-permeability carbonate rock. The base of the system is generally either (1) glauconitic, calcareous, argillaceous to arenaceous rock that ranges in age from late Eocene to late Paleocene (fig. 9) or (2) massively bedded anhydrite that commonly occurs in the lower two-thirds of the Paleocene Cedar Keys Formation. Locally, near Brunswick, Ga., micritic limestone and argillaceous limestone of Late Cretaceous (Tayloran) age mark the base of the aquifer system. The permeability of the micritic and argillaceous carbonate rocks, the anhydrite beds, and the various clastic rocks that comprise the base of the system is much less than that of the carbonate rocks above. Regardless of its lithologic character, the lower confining unit, whose top is mapped in this report as the base of the aquifer system, everywhere separates the system from deeper, predominantly clastic aquifers of early Tertiary and Late Cretaceous age.

The upper confining unit of the Floridan aquifer system generally consists of rocks of middle and late Miocene age. Where older rocks such as the lower Miocene Tampa or Oligocene Suwannee Limestones are of low permeability, they are also included in the upper confining unit. In parts of the study area, the upper confining unit has been removed by erosion and the aquifer system either: crops out, is covered by only a surficial sand aquifer, or is covered very locally by clayey residuum. Hydraulic conditions within the aquifer system accordingly vary from confined to unconfined. Where thick sequences of less permeable rocks of subregional extent are present within the aquifer system, they divide it into two major aquifers. The uppermost aquifer (Upper Floridan) generally consists of rocks of Oligocene, late Eocene, and late middle Eocene age (fig. 9). The lower aquifer (Lower Floridan) generally consists of rocks of early middle Eocene to late Paleocene age. Where no middle confining unit separates the two aquifers, all the permeable rock comprising the aquifer system is referred to as the Upper Floridan aquifer. The middle confining unit separating the Upper and Lower Floridan aquifers is generally found in the middle part of rocks of middle Eocene age. The less permeable material that comprises the middle confining unit, however, is not everywhere of the same age (fig. 9), nor does it everywhere consist of the same rock type, as a later section of this report discusses in detail.

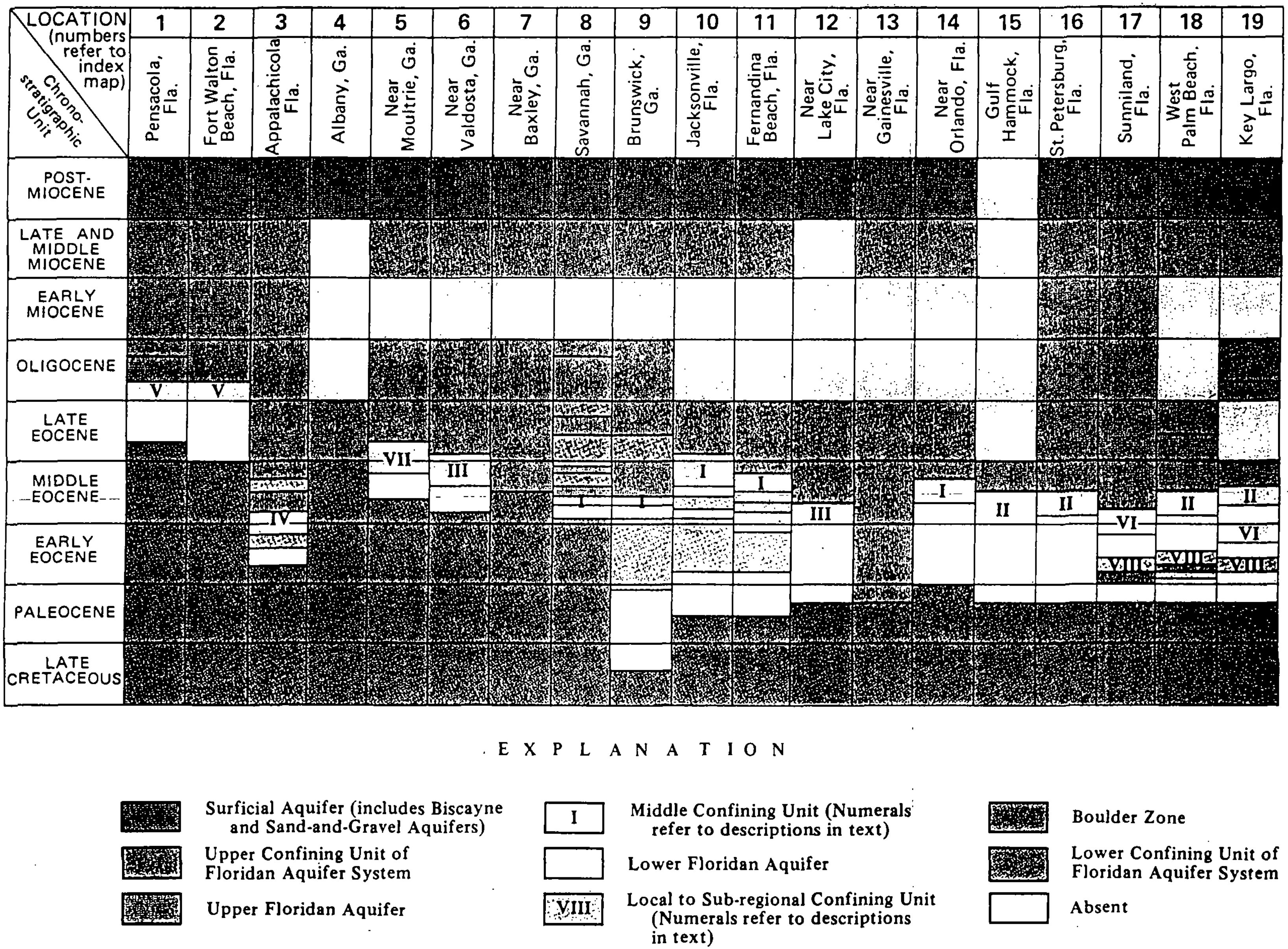


Figure 9. Relation of time-stratigraphic units to the Floridan aquifer system, its component aquifers, and its confining units.

Throughout much of the study area, the water in the Lower Floridan is brackish to saline. The Lower Floridan is moderately to highly porous, and digital simulation indicates that it transmits water sluggishly (see Bush and Johnston, 1985). Little is known about the Lower Floridan aquifer because in most places there is no reason to drill into a deep aquifer containing poor-quality water when an adequate shallower source of good-quality water (the Upper Floridan aquifer) exists.

Local to subregional zones of cavernous permeability occur at several levels within the Floridan aquifer system. The best known of these zones, called the "Boulder Zone" (Kohout, 1965) because of its difficult drilling characteristics, is found in the lower part of rocks of early Eocene age (fig. 9) in southern Florida. Borehole televiewer surveys show that this zone consists of a series of thin to moderately thick horizontal openings connected vertically by fractures, some of which have been opened and enlarged into vertical tubes by solution. The Boulder Zone resembles modern cave systems and is presumed to have formed in a similar fashion—by solution at or above an early Eocene paleowater table. As a result, the transmissivity of the Boulder Zone is extremely high (Meyer, 1974). Other shallower, less extensive cavernous zones are found farther north in the Florida peninsula (Miller, 1979). Where these cavernous zones are developed in the parts of the aquifer system that contain saline water, they are used as receiving zones for underground injection of treated sewage and other industrial wastes.

Within the sequence of rocks that is here treated as an upper confining unit are permeable zones that extend over part of a county or over several counties and that are important local sources of water. These localized artesian aquifers are considered in this report to comprise part of the upper confining unit of the Floridan aquifer system because their permeability is low in comparison with that of the Floridan and because they are of limited extent.

EXTENT

The Floridan aquifer system becomes thin in updip areas where it is interbedded with clastic rocks. The limestones that comprise the aquifer system grade in an updip direction into sandy or argillaceous limestone, which in turn grades into calcareous sand or clay. Still farther updip, these calcareous clastic rocks grade into fully clastic sediments that are stratigraphically equivalent to the aquifer system but are much less permeable than their limestone equivalents. The updip facies change from limestone into clastic rocks and the corresponding decrease in the amount of highly permeable rock in an updip direction are shown by geohydrologic cross-sections A-A', B-B', C-C', D-D' and O'-O'' (pl. 15, 16, 18, 19, 20). The updip limit of the Floridan aquifer system (plate 26) has been arbitrarily placed where the thickness of the system is less than 100 ft and where the clastic rocks interbedded with the limestone make up more than 50 percent of the rock column between the uppermost and lowermost limestone beds that can be shown to be connected downdip. To the north and west of the line shown as the approximate updip limit of the aquifer system, thin beds, lenses, and stringers of limestone may be either connected to the main limestone body or isolated from it because of postdepositional erosion. Although these thin beds and outliers locally yield water in small to moderate amounts, they are not considered in this report to be part of the Floridan aquifer system.

The Floridan aquifer system is known to extend offshore from Georgia (McCollum and Herrick, 1964) and peninsular Florida (Rosenau and others, 1977; Schlee, 1977; Johnston and others, 1982). Because offshore geologic and hydrologic data are sparse, however, the aquifer system is not mapped offshore in this report. The Floridan contains fresh to brackish water in some offshore areas (Johnston and others, 1982), but sparse data on water quality mandate mapping of the aquifer system's freshwater-saltwater interface by indirect methods (Bush and Johnston, 1985; Sprinkle, 1985).

In part of the mapped area in South Carolina, the Upper Floridan aquifer has passed by facies change into low-permeability clastic rocks, and only the Lower Floridan aquifer is present. The effect is that of a pinchout of the Upper Floridan. The approximate area of facies change within the Upper Floridan is shown on plate 26 by a dashed northwest-trending line whose location is based on widely scattered well control. Contours to the northeast of the line represent the top of a middle confining unit that is underlain by the Lower Floridan aquifer at an altitude several hundred feet lower. Other water-bearing limestone units in South Carolina are located northeast of the area mapped in this report, but they are either hydraulically separate from the Floridan aquifer system or their permeability is too low to warrant including them in the system.

A series of faults in southwestern Alabama shown on plate 26 marks the updip limit of the aquifer system. These arcuate faults, which are part of the Gilbertown-Pickens-Pollard fault zone, bound a series of grabens. Movement along these faults has juxtaposed low-permeability clastic rocks within the grabens opposite the permeable limestone that comprises the aquifer system. The north-trending, sinuous, fault-bounded feature in Washington and Mobile Counties,

Ala., is the Mobile Graben (Murray, 1961). Thin limestone beds within this graben have been downdropped and isolated from the main body of limestone. Farther westward, in southeastern Mississippi, the Floridan aquifer system passes by facies change into clastic rocks. The aquifer system is not mapped in Mississippi because it is insignificant there. Well data offshore from Mobile Bay, Ala., show that the Floridan is absent (again due to facies change) about 60 mi offshore.

CONFIGURATION AND CHARACTER OF TOP

Where the carbonate rocks that are included in the Floridan aquifer system crop out, their extent has been mapped in detail (Bennison, 1975; Copeland, 1968; Georgia Geological Survey, 1976; Vernon and Puri, 1965). The configuration of the surface of the aquifer system and the extent of the different rock units comprising its top are mapped in this report on the basis of the well control shown on plate 26, which is modified from a similar map by Miller (1982a). Detailed contouring in areas of sparse well control is based on data and maps found in published reports. The altitude of the top of the aquifer system may differ locally from the altitudes shown on plate 26 because local irregularities that have been produced by erosion or solution of the limestone may be present on the system's surface.

Plate 26 shows many localized topographic highs and lows on the aquifer system's surface in and adjacent to outcrop areas. These small features result from a combination of topography that developed when the limestone was exposed to subaerial erosion and karst topography that developed by subsurface solution of the limestone either while it was exposed or while it was buried at a shallow depth. If a smaller contour interval had been used on plate 26, many more sinkholes, solution valleys, and other types of karst features would be evident. The purpose of plate 26, however, is to show the regional configuration of the top of the Floridan aquifer system. Many of the references listed in this report contain maps that show the local topography of the aquifer system's surface in greater detail.

Because high permeability is the major criterion used in this report to delineate the top of the Floridan aquifer system, plate 26 differs locally from previously published maps (Vernon, 1973; Kwader and Schmidt, 1978; Buono and Rutledge, 1979; Knapp, 1979; Scott and Hajishafie, 1980) that show the configuration of either the top of vertically continuous limestone or the top of a specific geologic unit without regard to the permeability of the rock. In this report, any low-permeability rocks at the top of the carbonate sequence are excluded from the aquifer system. Within any of the areas where a given time-stratigraphic unit is mapped as the top of the aquifer, one- or two-well anomalies may occur if the particular time-stratigraphic unit is of low permeability throughout. Such isolated anomalies do not affect the general (regional) definition and configuration of the aquifer system and thus are not shown on plate 26.

The top of the aquifer system in most places is comprised of rocks of either Oligocene age (Suwannee Limestone or equivalent) or late Eocene age (Ocala Limestone or equivalent). Rocks of Oligocene age are thought to have once covered the entire area because (1) isolated erosional remnants of Oligocene strata are preserved as outliers surrounded by upper Eocene (Ocala) limestone and (2) a major marine transgression took place in the central and eastern Gulf Coastal Plain during Oligocene time, possibly related to a global rise in sea level (Vail and others, 1977). Post-Oligocene erosion, however, has stripped the Suwannee Limestone and equivalent strata from much of the mapped area, and left upper Eocene rocks widely exposed in outcrop and subcrop. Small patches of middle Eocene rocks that comprise the top of the aquifer system in central and southern peninsular Florida have been likewise exposed by erosion and protrude through a thin veneer of late Eocene strata because the younger rocks that once covered them have been stripped away. The area from which Oligocene rocks have been removed largely coincides with the axis and flanks of the Peninsular arch, and their absence is probably due to a slight rejuvenation or upwarp of this arch. Smaller structural features, such as some of the faults in peninsular Florida, have provided sufficient relief for younger rocks to be stripped and for older sediments to be exposed on the upthrown sides of the faults. By contrast, Oligocene outliers in southeastern Alabama (pl. 26) are not related to structure but reflect present-day topography and erosion.

Throughout most of Georgia and in north-central Florida, all rocks of Oligocene age are highly permeable and are included in the Floridan aquifer system. Accordingly, in these areas, the top of Oligocene strata coincides with the top of the aquifer system. In parts of southern Alabama, panhandle Florida, and the southern part of the Florida peninsula, the upper part of the Oligocene section consists of either low-permeability (commonly micritic) limestone or clastic rocks or both and is therefore not included in the aquifer system. In these places, then, the top of the system lies within rocks of Oligocene age rather than at their top.

Rocks of late Eocene age (Ocala Limestone) are present throughout most of the study area, are highly

permeable practically everywhere, and comprise the top of the aquifer system over much of its extent (pl. 26). Upper Eocene rocks are excluded from the system only in South Carolina, where they are highly argillaceous and grade into part of the Cooper Formation, and very locally in southern Florida, where all or part of the Ocala Limestone is micritic and its permeability is accordingly low. With these exceptions, where upper Eocene rocks are present, they yield large quantities of water everywhere. In extreme western panhandle Florida, low-permeability rocks occur in the lower part of the upper Eocene section because upper Eocene limestone there passes into clastic rocks through facies change.

There are a few localities in peninsular Florida where both Oligocene and upper Eocene rocks are absent (pl. 26). In these places, middle Eocene rocks (Avon Park Formation) comprise the top of the Floridan aquifer system. Like upper Eocene rocks, the upper part of the middle Eocene section is generally highly permeable, except in updip areas where there is a transition of middle Eocene limestone into clastic sediments. In much of South Carolina, a thin unit of limestone that lies within the middle Eocene (part of the Santee Limestone) comprises the entire permeable part of the aquifer system; here, younger strata are either clastics or low-permeability carbonates or both. The top of the middle confining unit is mapped here as the top of the aquifer system.

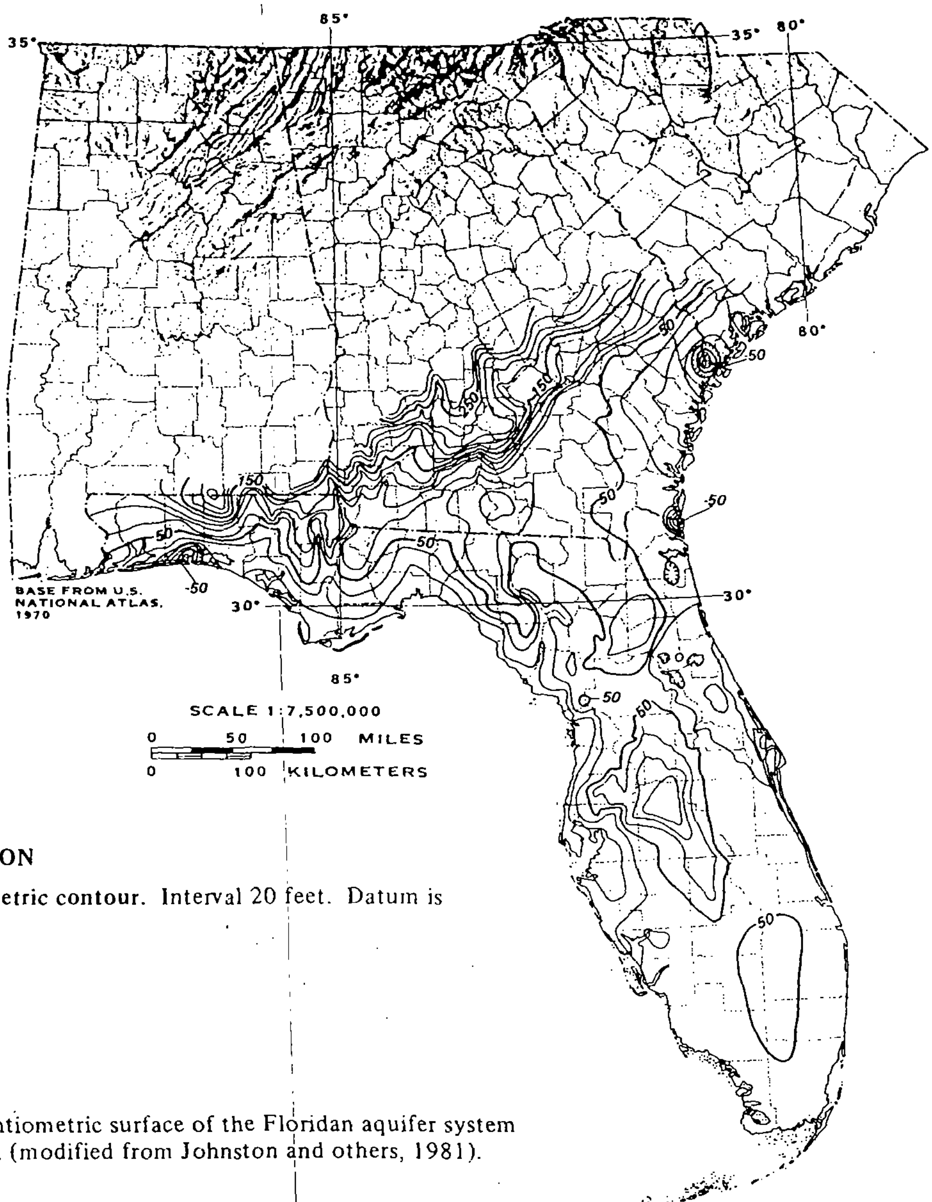
Rocks of early Miocene age (Tampa Limestone and its equivalents) mark the top of the aquifer system in a small area along the central part of peninsular Florida's Gulf Coast and in a larger area in eastern panhandle Florida. Although the area over which lower Miocene rocks are present is considerably wider than that mapped on plate 26, only within the mapped area are they permeable enough to be included as part of the Floridan aquifer system.

Even though plate 26 is a composite of several time-stratigraphic levels, major geologic structures are shown as large-scale features on the map and are generally expressed as a series of broad high and low areas that interrupt the steady, gentle seaward slope of the aquifer system's top. For example, the Southeast Georgia embayment is shown as an east-trending negative area centered near Brunswick, Ga.; the low area in and near Gulf County, Fla., is part of the Southwest Georgia or Apalachicola embayment; the low areas in central Lee County and northern Monroe County, Fla., are arms of the South Florida basin. The influence of the Gulf Coast geosyncline is reflected as a steep, steady gulfward slope of the top of the aquifer system in extreme western panhandle Florida and in southern Alabama.

Parallel to northern peninsular Florida's western coast and extending for a short distance into sout western Georgia is an elongate, broad, northwe trending high area. This high, known in the literatu as the Ocala uplift, has been thought to represent arch or an anticline, partly because, like a class anticline, older rocks are exposed near its "axis." Th "axis," although clearly shown on a map of the surfa of rocks of late Eocene age (pl. 8), is not present on map of the top of rocks of middle Eocene age (pl. 6), n does it occur on maps of older geologic units or on map of the base of the aquifer system (pl. 33). Th author agrees with Winston (1976) that the Oca uplift is not a structural uplift in the classic sense. T "uplift" may reflect post-Eocene tilting of the Floric peninsula, as Winston proposed, or it may be mere the result of differential compaction of soft carbona rocks over an irregular depositional surface.

A subtle positive feature in extreme southeaste Alabama and southwestern Georgia (pl. 26) is in t same location as the feature that has been called t Chattahoochee arch or anticline by some authors. Th positive area is not shown on maps of the tops thicknesses of the several time-stratigraphic units th comprise the aquifer system (pls. 3-11), nor is it prese on a map of the base of the system (pl. 33). Patterso and Herrick (1971), after reviewing all published ev dence, concluded that the Chattahoochee anticline w hypothetical rather than real. This author agrees th there is no evidence for a structural feature where th "anticline" is supposedly located and concludes th the apparent "structure" is in fact an erosional featur perhaps exaggerated by a change in the strike of t outcropping coastal plain rocks from a northeaste alinement along the Atlantic Coastal Plain to an eas west alinement along the Gulf Coastal Plain.

In addition to the faults in Alabama that form pa of the updip limit of the Floridan aquifer syste several small faults concentrated in eastern peninsul Florida and central Georgia are shown on plate 26. T locations of the faults shown in Florida were tak from the literature and changed slightly where it w necessary to conform with well data. Most of t Florida faults are downthrown on the oceanward si and all appear to be normal or gravity faults. All of t faults shown displace rocks of late Eocene age, and least one, in southern Florida, which extends fr Indian River County southeast to Martin County, post-Oligocene in age. From Volusia County sou ward, younger rocks have commonly been eroded fr the upthrown sides of these faults, and older str have thus been exposed in subcrop. None of t Florida faults mapped has a major effect on the fl system of the Floridan, as a comparison of the pote ometric surface (fig. 10) with the fault locations plate 26 shows. All of the faults are of small displa



EXPLANATION

—150— Potentiometric contour. Interval 20 feet. Datum is sea level

Figure 10. Potentiometric surface of the Floridan aquifer system in May, 1980. (modified from Johnston and others, 1981).

ment, and where they occur, the upper few hundred feet of the aquifer system is highly permeable, regardless of which time-stratigraphic unit it lies within. Fault movement has accordingly juxtaposed rocks of similar permeability and has resulted in only a slight difference in the thickness of the aquifer system. The ground-water flow system is accordingly unaffected.

When the small northeast-trending grabens shown in central Georgia on plate 26 are taken together, they represent a negative feature called by Herrick and Vorhis (1963) the "Gulf Trough of Georgia," a name subsequently shortened to "Gulf Trough" (Hendry and Sproul, 1966). Herrick and Vorhis did not postulate faulting as the cause of the Gulf Trough. Gelbaum (1978) and Gelbaum and Howell (1982), however, indicated that faulting could have formed many if not all of the small elongate basins that constitute the Gulf Trough, an interpretation with which this author agrees. In contrast to the Florida faults discussed above, the faults bounding the Gulf Trough grabens show considerable vertical displacement. The graben system affects the permeability characteristics, the thickness, and the configuration of the top of the Floridan aquifer system, and is also evident on maps of the tops and thicknesses of stratigraphic units ranging in age from middle Eocene to middle Miocene. Limestone units that are part of the aquifer system are less permeable within the Gulf Trough those than on either side (Gelbaum and Howell, 1982), and the system is thin within the trough (pl. 27).

The Gulf Trough coincides with a bunching of contours on a map of the potentiometric surface of the Floridan aquifer system (fig. 10). Such a steep hydraulic gradient can be caused by a decrease in transmissivity. Very low specific capacities for Floridan wells within the trough suggest that the aquifer system is less transmissive there; ground-water modeling tends to confirm this suggestion. The grabens that comprise the trough are bounded by steeply dipping normal faults. Displacement along these faults has downdropped low-permeability Miocene clastic sediments within the grabens opposite the permeable limestone that borders the grabens on both sides (pl. 26). The result is a damming effect at the trough on the generally southeast-flowing ground water within the Floridan. The combination of low-transmissivity limestones in the grabens and the retardation of flow by the juxtaposition of a thick sequence of low-permeability clastic rocks opposite the limestone accounts for the steep hydraulic gradients that exist in the aquifer system in the Gulf Trough area.

THICKNESS

The Floridan aquifer system generally thickens seaward from a thin edge near its approximate updip limit. Plate 27, updated and modified from a map by Miller (1982b), shows the thickness of the entire aquifer system, including the Upper and Lower Floridan aquifers and the middle confining unit that separates them. The thickness mapped includes all strata between the top of the highest vertically continuous permeable limestone sequence (top of the aquifer system) and the top of the low-permeability clastic or evaporitic rocks that form the base of the system. Well point data have been used primarily to construct the thickness map and have been supplemented in areas of sparse well control by thickness estimates obtained by subtracting contoured elevations of the top and base of the aquifer system (pls. 26, 33). Thicknesses may vary locally from those shown, especially where erosion or karst topography has created considerable relief on the aquifer system's surface.

The Floridan aquifer system is composed of all or parts of several different formations and (or) time-stratigraphic units in different combinations at different places. Plate 27 therefore represents a composite thickness that may encompass only a part of a single formation in updip areas or may include several time-stratigraphic units downdip. Because the aquifer system is defined primarily by the occurrence of permeable carbonate rocks, plate 27 cannot be interpreted in exactly the same way as an ordinary isopachous map. Some of the thickening and thinning trends shown on the map are, however, related to depositional conditions and geologic structure. Some of the large-scale structures in the mapped area have maintained their relative positive or negative character over long periods of geologic time. For this reason, and because movement on these features kept pace with depositional rates, basin conditions remained very much the same, and thick sequences of carbonate rocks of similar lithology were deposited. The major structural features in the study area shown on plate 27 are areas of major thickening or thinning of the aquifer system.

The Floridan aquifer system is typically composed of platform carbonate rocks that were deposited in warm, shallow water as limestones of various textures and were subsequently dolomitized in varying degrees. This platform carbonate sequence is best developed to the south and east of the 1,000-ft thickness contour shown on plate 27. North and west of this contour, the carbonate rocks interfinger with clastic sediments in an area that represents spillover of carbonate deposition onto a foreland basin that was receiving clastic sediments from a landmass to the north and west. In upbasin areas, this dual source of sediment supply resulted in complex interbedding and interfingering of clastic and carbonate rocks. As the carbonate rocks thin toward the updip limit of the aquifer, the amount of clastic material admixed with them increases. These factors account for the lower permeability and transmissivity (Bush and Johnston, 1985) of the aquifer system in an upbasin direction.

In north-central peninsular Florida (pl. 27), the limestone units that comprise the aquifer system thin over the crest and flanks of the Peninsular arch. The great thicknesses of carbonate rocks in the eastern panhandle of Florida and in southeastern Georgia have accumulated in the Southwest and Southeast Georgia embayments, respectively. The thick area in Manatee and Sarasota Counties, Fla., is thought to be part of the South Florida basin. The thick area in southern Martin County, Fla., does not correlate with any known structural feature; the aquifer system is thick simply because the anhydrite beds that mark its base in southern Florida are exceptionally deep. The aquifer system does not thicken greatly in a gulfward direction in western panhandle Florida and southern Alabama, as one might expect. The supply of clastic sediments from the north and west was great enough here to preclude the deposition of limestone throughout most of that the time the aquifer system was being formed.

A small graben system in central Georgia cuts through the entire thickness of the aquifer system (section B-B', pl. 16), and was apparently active during as well as after deposition of the limestone that makes up the system. The series of small grabens shown on plate 27 comprises the Gulf Trough discussed earlier.

For the most part, there are more clastic rocks and low-permeability limestone within these grabens than there are to the northwest and southeast of the normal or gravity faults that bound them. Because of the greater amount of clastic material in the grabens, the aquifer system is much thinner within them. For example, near Moultrie in Colquitt County, Ga., the aquifer system is less than 200 ft thick within one of the grabens but is more than 500 ft thick to the northwest, in an upbasin direction where the aquifer system would normally be expected to be thinner.

Movement along the faults of the graben system has downdropped low-permeability clastic rocks within the grabens opposite permeable limestone on either side of them. This juxtaposition has restricted the flow of ground water across the grabens and down the hydraulic gradient from them. Throughout the shaded area shown on plate 27 (southeast of the graben system and extending from Gadsden County, Fla., northeast to Berrien County, Ga.), the aquifer system is thin and consists of only a few hundred feet of permeable limestone underlain by gypsiferous limestone. The ground-water flow across this area, restricted by the grabens to the northwest, has not been sufficient to completely dissolve the gypsum contained in the limestone.

In southwestern Alabama, the arcuate faults shown on plate 27, like those in central Georgia, bound a series of grabens. Gulfward of these grabens (except in southern Mobile County, Ala.), there is very little limestone; thick sequences of clastic rocks in the grabens and seaward of them are the Floridan aquifer system's equivalent.

An oval-shaped northeast-trending thick pod of limestone in Clinch and Echols Counties, Ga., possibly represents the Suwannee Strait, a poorly understood channel-like feature that was once thought to separate predominantly clastic rocks to the northwest from predominantly carbonate rocks to the southeast. Because the feature as mapped on plate 27, is closed to the northeast and southwest, it is obviously not a channel. Its exact origin is not known, however.

There are several local, flat, shelflike features shown on plate 27 in southern Florida. The most prominent are just south of Miami in Dade County, north of Fort Pierce in St. Lucie County, and in Lee County. These shelflike areas are apparent, not real, and are the result of differences in elevation of the evaporite deposits that comprise the base of the aquifer system in southern Florida. These low-permeability evaporites occur at different altitudes in different wells because they interfinger with carbonate rocks as a series of discrete large lenses. Regionally, the lenses are mapped as if they were a single horizon, and their interfingering nature creates the illusion of irregular topography. The anhydrite that represents the base of the Floridan aquifer system is high under all these shelflike areas, and the aquifer system above these high spots is accordingly thin.

MAJOR HYDROLOGIC UNITS WITHIN THE FLORIDAN AQUIFER SYSTEM

The Floridan aquifer system is extremely complex because (1) the rocks that comprise it were originally laid down in highly variable depositional environments, and their texture and mineralogy accordingly vary considerably; (2) diagenesis has produced much change in the original sediments in places, and (3) large- to small-scale karst features are developed at several levels in the aquifer system owing to modern and ancient dissolution of the limestone. These factors, alone or in combination, create much local variability in the aquifer system's lithology and permeability characteristics. It is necessary, therefore, to generalize greatly both the geology and the hydraulic parameters of the aquifer system to present a regional view of each. Also, to simulate regional ground-water flow with a digital computer model, the complexities of local variations in geology and hydraulic properties must be simplified. Regionally, as mentioned earlier (section "Floridan Aquifer System"), the Floridan aquifer system generally consists of an Upper and a Lower Floridan aquifer separated by a middle confining unit. Neither the separate aquifers nor the middle confining unit is everywhere the same thickness or age or necessarily consists of the same type of rock. In places, no middle confining unit exists, and the entire aquifer system is more or less permeable. In other places, such as southern Florida, most of the aquifer system consists of low-permeability rocks separating thin zones of high permeability. Within regionally extensive aquifers or confining units, there may be from one to several local zones of contrasting permeability (see, for example, section E-E', pl. 21); these local zones, however, do not usually affect the overall character of the given aquifer or confining unit, even though a given zone may locally have an important hydraulic influence.

The upper major permeable zone of the aquifer system, herein called the Upper Floridan aquifer, yields large volumes of water nearly everywhere, and the water is usually of good chemical quality. As a result, few water-supply wells penetrate the aquifer system's middle confining unit and the Lower Floridan aquifer, which lie at considerable depth. The hydrologic character of these deeper parts of the aquifer system is therefore known from only a few scattered deep wells, most of which were constructed to test their

potential for waste injection. Because all the numerous oil test wells in the study area completely penetrate both the Floridan aquifer system and its lower confining unit, however, the geologic character of the aquifer system's deep zones is better defined. Accordingly, the hydraulic properties of the deeper parts of the aquifer system are inferred in large part from their geologic character. The major high- and low-permeability zones within the aquifer system that are of regional extent are discussed in order from shallowest to deepest.

Upper Floridan Aquifer

The configuration and character of the top of the Upper Floridan aquifer are discussed in the section describing the top of the system. The time-stratigraphic units that compose the Upper Floridan aquifer at various places are shown in figure 9. Hydraulic head and water-quality data show that, where the Upper and Lower Floridan aquifers are in contact (that is, where there is no appreciable thickness of low-permeability rock between them), they behave as a single hydraulic unit. Where the aquifer system's middle confining unit is absent, the base of the Upper Floridan aquifer is actually the base of the entire aquifer system, and, likewise, the thickness of the Upper Floridan aquifer equals the thickness of the entire system.

The Upper Floridan aquifer generally consists of all or part of rocks of Oligocene age (mostly the Suwannee Limestone), rocks of late Eocene age (mostly the Ocala Limestone), and rocks of middle Eocene age (mostly the upper part of the middle Eocene). Locally, (for example, near Gainesville, Fla. column 13, fig. 9), all rocks of middle Eocene age, rocks of early Eocene age (mostly the Oldsmar Formation), and the upper part of strata of Paleocene age (mostly the Cedar Keys Formation) are included in the Upper Floridan aquifer in those places where the aquifer system's middle confining unit is not present. At a few locations (for example, column 16, fig. 9), rocks of early Miocene age (Tampa Limestone and equivalents) are permeable enough to be considered part of the Upper Floridan aquifer. Data collected during this study show that the permeability of the rocks included in the Upper Floridan aquifer is much higher than that of those comprising the Lower Floridan aquifer, with the exception of southern Florida's Boulder Zone, a zone of cavernous permeability encompassed within the Lower Floridan.

The thickness of the Upper Floridan aquifer as shown on plate 28 (modified from a map by Miller (1982d)) represents all strata that lie between the top of the highest vertically continuous permeable limestone (top of the Floridan aquifer system) and the base of either the Upper Floridan aquifer, where a regionally extensive middle confining unit exists, or the base of the entire aquifer system, where no appreciable thickness of low-permeability rock is present. This single aquifer condition (no separation of the aquifer system into upper and lower major permeable zones) exists in the patterned area shown on plate 28. The thickness values contoured on plate 28 were obtained primarily from well data, but, in areas of sparse control, the contouring has been supplemented by estimates obtained by subtracting contoured elevations of the top of the aquifer system (pl. 26) and the base of the Upper Floridan aquifer (pl. 29).

It is important to reiterate that the Upper Floridan aquifer, like the other major high- and low-permeability zones within the Floridan aquifer system, is delineated on the basis of permeability characteristics. Thus, neither the top nor the base of the Upper Floridan necessarily conforms to formation or time-stratigraphic boundaries. This situation is particularly true of the base of the Upper Floridan (fig. 9). The lithologic character of the rocks comprising the base of the Upper Floridan varies greatly, and accordingly, the rocks vary in their effectiveness as a confining unit. The vertical hydraulic conductivity of the rocks that comprise the base of the Upper Floridan, however, is everywhere at least two orders of magnitude less than that of the aquifer material itself. Because plate 28 represents the thickness of rocks of similar (high) permeability, interpretation of the map is different from that of the usual isopachous map. For example, thick sequences of rocks shown on plate 28 do not necessarily lie in downbasin positions, the situation commonly encountered on an ordinary thickness map. Rather, because sediments ordinarily become finer grained and correspondingly less permeable in a downbasin direction, greater thicknesses of permeable rock may occur in updip areas.

The altitude of the low-permeability rocks that mark the base of the Upper Floridan aquifer is the major factor affecting the thickness values shown on plate 28. Where the base occurs at shallow depths, the Upper Floridan is thin; where the base is deep, the aquifer is thick. The lines of equal thickness are irregular and, where they are closed, delineate numerous small, isolated thick or thin spots in places where the Upper Floridan as a whole is less than 400 ft thick. These small features are the result of erosion and (or) karst topography developed on the aquifer system's surface.

Plate 28 shows that the Upper Floridan aquifer is thin (1) in and near those places where the aquifer system crops out, (2) throughout roughly the western half of panhandle Florida, and (3) in a wide band

parallel to the Atlantic coastline. Near the outcrop area, the limestone that comprises the aquifer thins and grades into clastic rocks in an updip direction. The two other widespread thin areas represent places where the aquifer system's middle confining unit (base of the Upper Floridan aquifer) lies at shallow depths. The greatest thickness of the Upper Floridan is along the north-central part of Florida's Gulf Coast and is part of the area where all of the rocks included in the aquifer system are permeable (the Upper and Lower Floridan aquifers merge). Areas of intermediate thickness adjacent to peninsular Florida's Gulf Coast and straddling the central part of the Florida-Georgia border reflect different altitudes of the aquifer system's middle confining unit.

In some places, the Floridan aquifer system contains two or more regionally extensive middle confining units, which lie at different depths and are separated by permeable rocks. An example of this situation occurs in the central part of peninsular Florida and is shown on plate 28; dashed contact lines show places where a deeper low-permeability zone is overlain by a shallower overlapping confining unit. Here, a band of low-permeability rock parallel to the Atlantic Ocean lies at an altitude several hundred feet higher than that of a western low-permeability zone that extends to the Gulf of Mexico. Where such an overlap occurs, the top of the shallower low-permeability unit is considered to be the base of the Upper Floridan aquifer. Geohydrologic cross section G-G' (pl. 23) shows this overlap in the third dimension. Farther north, the same two confining units are present (cross section F-F', pl. 22) but do not overlap.

Several major structural features are known to exist in the mapped area, but not all of them appear on plate 28. The area in Gilchrist and Lafayette Counties in northern Florida where the Upper Floridan aquifer is thin may represent the Peninsular arch. The thick area in southern Wakulla County, Fla., is probably part of the Southwest Georgia embayment. Aside from these two examples, no other major structures appear to coincide with variations in the Upper Floridan's thickness. Several small faults reflected by local anomalies in regional thickening trends of the Upper Floridan include the Gulf Trough graben system in central Georgia and a small-displacement normal fault in southern peninsular Florida. The faults shown in southwestern Alabama cut, displace, and in part mark the updip limit of the Upper Floridan aquifer.

Preliminary results from a digital model of the aquifer system (Bush, 1982) show that most of the ground-water circulation in the system takes place in the Upper Floridan aquifer. The water in the Upper Floridan is nearly everywhere less mineralized than that from deeper zones in the aquifer system (Sprinkle, 1985), largely because of more vigorous circulation of water in the Upper Floridan. The high permeability that permits this vigorous circulation results from high intergranular or moldic porosity in the Suwannee, Ocala, and Avon Park rocks comprising the Upper Floridan, coupled with much secondary porosity (mostly large dissolution cavities).

MIDDLE CONFINING UNIT

There are eight low-permeability units of subregional extent that lie within the Floridan aquifer system in the study area. Seven of these units separate the Upper Floridan aquifer from the Lower Floridan aquifer. The remaining unit lies within the Lower Floridan aquifer and is discussed in the following section describing that aquifer. Any or all of the subregional low-permeability units may locally contain thin zones of moderate to high permeability. Overall, however, the units act as a single confining unit within the main body of permeable limestone that constitutes the aquifer system. In much of southern Florida, several thick low-permeability units occur within the aquifer system—so many, in fact, that in places the strata that constitute the system are mostly low-permeability rocks containing a few high-permeability zones (see, for example, sections B'-B″ and H-H', pls. 17, 24). These zones show hydraulic head differences, contain water of somewhat different quality, and behave differently in response to natural and pumping (or injection) stresses. In places where two or more of the subregional low-permeability units occur, the base of the shallower low-permeability unit is considered to be the top of the Lower Floridan aquifer.

The areal extent and altitude of the top of each of the seven confining units separating the Upper and Lower Floridan aquifers are shown on plate 29, which was modified from a map by Miller (1982b). Because, by definition, the middle confining unit of the aquifer separates the Upper and Lower Floridan aquifers, the contours shown represent the base of the Upper Floridan aquifer, which varies greatly in altitude from place to place. For convenience and because the confining units are not necessarily a part of the same formation and do not consist of the same rock type everywhere, each confining unit has been designated by a roman numeral on plate 29. Each unit will be referred to by its particular numeral in the text of this report, on a fence diagram (pl. 30) that shows the three-dimensional relations of the various high- and low-permeability units within the aquifer, and in figure 9, which shows the relative ages of each unit. Because none of the low-permeability units mapped on plate 29 crop out, the extent and character of the units have been determined solely on the basis of well control.

Where no middle confining unit is present, the Upper and Lower Floridan aquifers merge vertically and are mapped as part of the Upper Floridan aquifer. In such places, because no low-permeability rocks exist above the base of the aquifer system, that base is synonomous with the bottom of the Upper Floridan aquifer. The white area on plate 29 shows this condition. The contours shown in this area are thus the same as those shown on a map of the base of the aquifer system (pl. 33). Over the northern two-thirds of this area, the base of the Upper Floridan aquifer is marked by calcareous glauconitic sand and clay beds that are the equivalents of the outcropping middle Eocene Lisbon and Tallahatta Formations of Alabama and western Georgia. Farther southeast, the base of the Upper Floridan consists of calcareous clastic rocks that are the equivalent of the lower Eocene Oldsmar Formation of Florida; in north-central Florida, anhydrite beds that are part of the Cedar Keys Formation underlie the Upper Floridan aquifer. The extent of each unit is shown on plate 33, and the units are discussed in more detail in the section of this report that describes the base of the aquifer system. In much of South Carolina (Colleton County and northward), the Upper Floridan aquifer pinches out, and the middle confining unit merges with the upper confining unit of the aquifer system. Accordingly, no middle confining unit is mapped north of the pinchout of the Upper Floridan.

Along the Atlantic Coast, an extensive band of low-permeability rocks (middle confining unit I, pl. 29) extending from southeastern South Carolina to the Florida Keys marks the base of the Upper Floridan aquifer. The strata that comprise unit I lie in the middle and upper parts of rocks of middle Eocene age (fig. 9). Very locally (for example, in the Jacksonville, Fla., area), the lower part of rocks of late Eocene age is included in unit I. From the Florida Keys northward to Liberty County, Ga., unit I consists of soft, micritic limestone and fine-grained dolomitic limestone, both of low porosity. North of Liberty County, these carbonate rocks grade laterally by facies change through calcareous sand and clay in northeastern Georgia northward into sandy clay in South Carolina. Figure 11 shows the approximate areal extent of the clastic and carbonate facies and the general configuration of the top of unit I throughout its known extent. Because the Upper Floridan aquifer pinches out in South Carolina, unit I merges with the aquifer system's upper confining unit north of this pinchout (fig. 12); the only permeable limestone in the extreme northeastern part of the mapped area is a thin bed that is part of the Lower Floridan aquifer. The contrast in permeability between the rocks of unit I and the permeable rocks above and below it is less than that for any other middle confining unit mapped. Accordingly, unit I is the leakiest confining unit known in the study area. The lithology of unit I is not much different from that of the permeable zones vertically adjacent to it, and the unit's original porosity has not been greatly affected by pore-filling secondary mineralization. There are minor variations in hydraulic head (Lichtler and others, 1968; Snell and Anderson, 1970) and water quality across unit I; these variations, together with flowmeter data (see, for example, Leve, 1970) from scattered wells, show that the unit acts as a confining bed. Unit I separates the Upper and Lower Floridan aquifers everywhere in east-central Florida, the area discussed by Tibbals (1985), and throughout roughly half of the contiguous area to the north that is discussed by Krause and Randolph (1985). In a narrow northwest-trending band in central peninsular Florida (pl. 29), unit I overlaps gypsiferous dolomite that comprises middle confining unit II, described below, and is separated from unit II by a few hundred feet of permeable rock (see cross section G-G', pl. 23). The areal extent of the overlap shown by the dashed contact line on plate 29 is approximate because it is based on well control.

In west-central peninsular Florida, the middle confining unit of the aquifer system consists of low-permeability gypsiferous dolomite and dolomitic limestone. This unit, labeled unit II on plate 29, occurs approximately in the middle of rocks of middle Eocene age. As mentioned earlier, unit II is overlapped by unit I in part of central Florida. The altitude of unit II throughout its known extent, including this area of overlap, is shown in figure 13. The gypsum that is responsible for the low permeability of unit II is largely intergranular and appears to fill preexisting pore spaces in the rock. Lenses, stringers, pods, and thin beds of gypsum are also present, however. The gypsiferous dolomite probably represents an extensive middle Eocene sabkha or tidal flat environment, although some of the intergranular gypsum may have been emplaced by gypsum-rich interstitial waters. Hydraulic data (Guyton and Associates, 1976) show that unit II forms an essentially nonleaky confining bed. Data from oil and deep injection test wells show that permeable rock everywhere underlies unit II. The highly mineralized water contained in this rock, which is part of the Lower Floridan aquifer, suggests poor interconnection with the freshwater of the overlying Upper Floridan. Figure 14 shows the thickness of unit II. Anamolously thick areas, such as those shown in Polk County, Fla., are thought to have been caused by incomplete dissolution of gypsum and anhydrite in places where the deep flow system is very sluggish. Thinner areas represent places where more vigorously circulating waters have dissolved much of unit II's

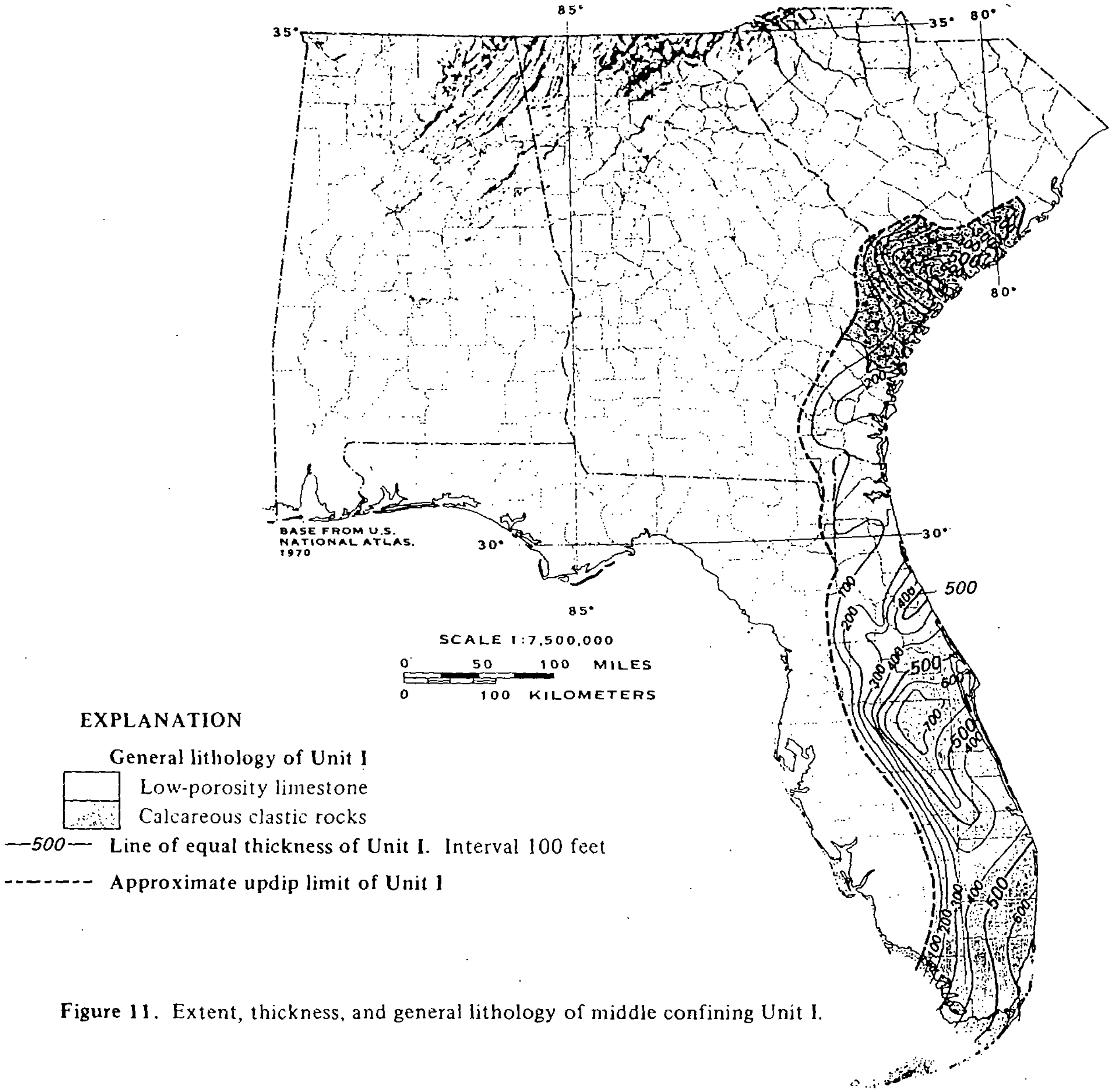


Figure 11. Extent, thickness, and general lithology of middle confining Unit I.

interstitial evaporitic material and thereby increased porosity and permeability. Unit II is treated as the base of the aquifer system in the subregional ground-water flow model discussed in by Ryder (1985) because (1) the unit is present throughout practically the entire area covered by the subregional model, (2) the unit has an extremely low permeability, and (3) the Lower Floridan aquifer below unit II is of relatively low permeability and contains poor-quality water. For the regional simulation described by Bush and Johnston (1985), however, the Lower Floridan aquifer that lies below unit II is treated as a high-permeability zone and is included as part of the ground-water flow system in west-central Florida, as it is elsewhere.

Along the central part of the Georgia-Florida border, the aquifer system's middle confining unit (unit III, pl. 29) consists of low-permeability, dense, fossiliferous, gypsiferous, dolomitic limestone that occurs in the lower or middle parts of rocks of middle Eocene age. The gypsum, like that found in unit II, is mostly intergranular, although it occurs rarely as layers and lenses within the limestone. Although small amounts of water can be obtained from unit III, the water is of poor quality owing to high sulfate concentrations that result from dissolution of the gypsum (see Sprinkle's (1985) map of sulfate concentration.) Concentrations of sulfate as high as 2,600 mg/L have been reported in ground water from unit II in Valdosta, Ga. (Krause,

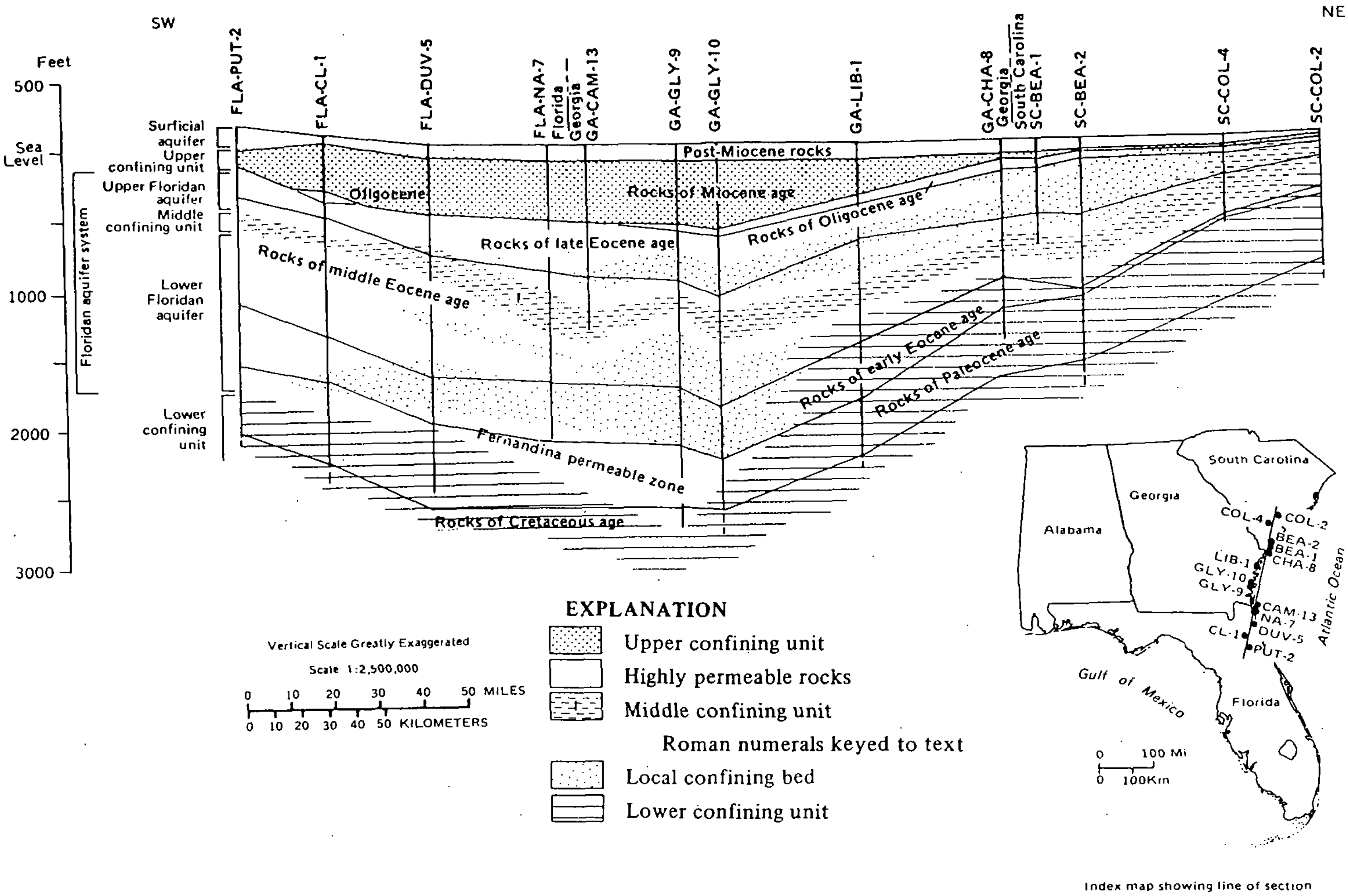


Figure 12. Generalized geohydrologic cross section from Putnam County, Fla. to Colleton County, S.C.

1979). Meyer (1962) recorded a sulfate concentration of about 1,100 mg/L in water from the same rocks near Lake City, Fla. Unit III is considered to be a slightly leaky confining bed. The extent and thickness of unit III are shown in figure 15. Where the thickness values shown in this figure exceed 200 ft, there are no permeable rocks below unit III; the gypsiferous rocks of the unit grade downward, without a break, into low-permeability clastic rocks that are part of the aquifer system's lower confining unit. This gradation is shown in cross section in figure 16. Elsewhere, especially near the edges of unit III, the gypsiferous limestone is underlain by permeable strata that are part of the Lower Floridan aquifer. No hydraulic or water-quality data exist for the Lower Floridan beneath unit III. Because the rock and permeability framework of the area underlain by unit III are similar to those underlain by unit II, the Lower Floridan aquifer under both areas is assumed to be similar: that is, under unit III the Lower Floridan is assumed to contain poor-quality water that is part of a slow-moving flow system. The subregional model that encompasses part of unit III (Krause and Randolph, 1985) does not consider the Lower Floridan aquifer under unit III to be a part of the ground-water flow system, for the same reasons that the Lower Floridan is excluded from the subregional model of Ryder (1985). In the regional simulation, however, the Lower Floridan, where it exists under unit III, is included as part of the flow system.

The rocks designated as middle confining unit IV (pl. 29) are deep-lying calcareous sand and clay, which in part grade northwestward into clastic rocks that are equivalents of the middle Eocene Lisbon and Tallahatta Formations, and the upper part of rocks of early Eocene age. Where unit IV is mapped, the Lower Floridan aquifer is present beneath the unit. Updip, the aquifer system consists of only one permeable zone that is treated as the Upper Floridan aquifer. Unit IV

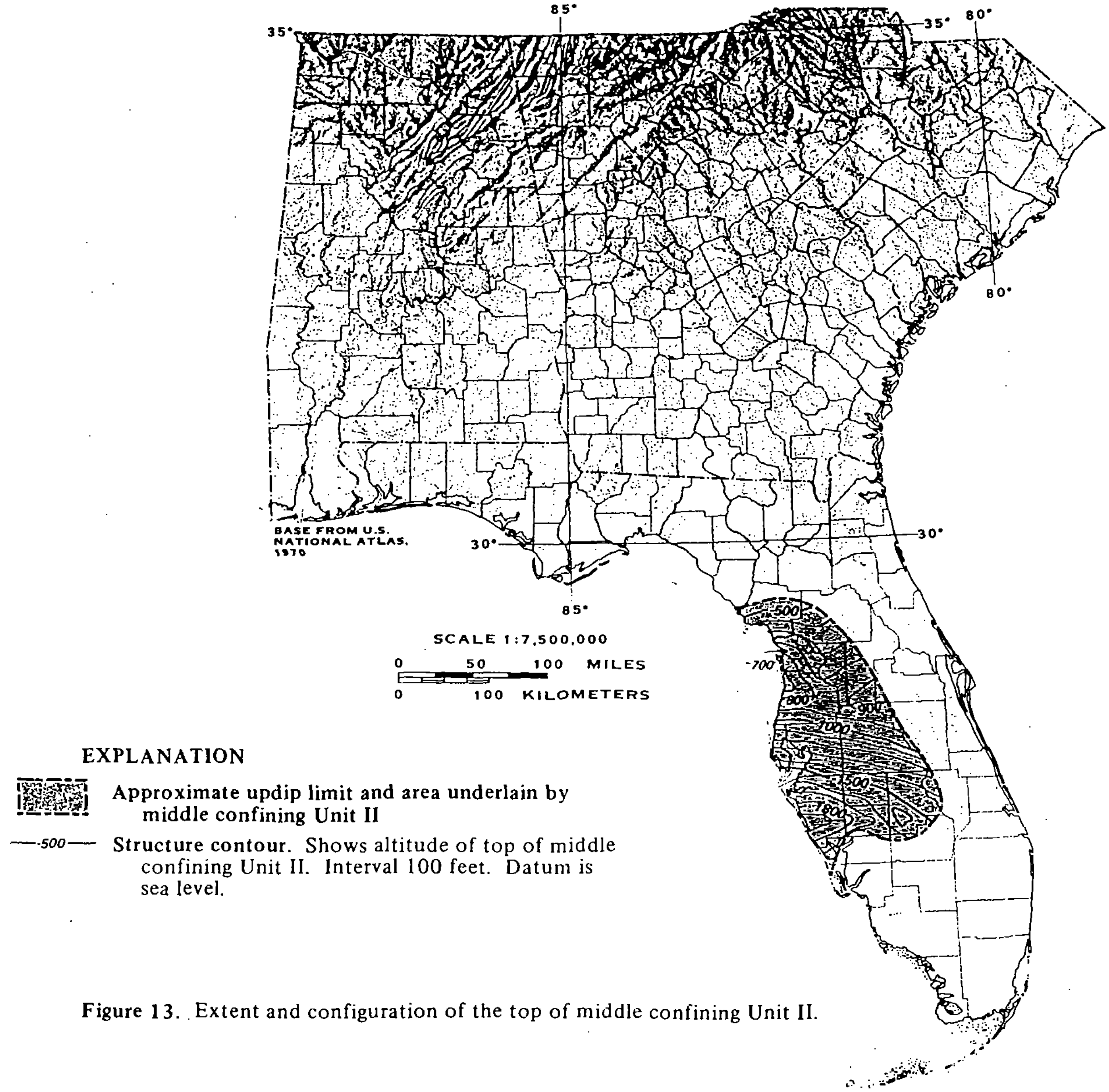


Figure 13. Extent and configuration of the top of middle confining Unit II.

represents a tongue of low-permeability rock extending into the aquifer system's permeable limestone, and locally dividing it into two discrete zones (cross section A-A, pl. 15). As figure 17 shows, the areal extent of unit IV is limited to a few counties in eastern panhandle Florida. There are no hydraulic head data available from which to determine the effectiveness of unit IV as a confining unit. The unit's lithologic character indicates that it is a relatively leaky confining unit whose ability to transmit water vertically is probably exceeded only by that of unit I. The Upper Floridan aquifer is very thick in the area underlain by unit IV (pl. 28). In fact, the greatest measured thickness of the Upper Floridan is from well FLA-GF-8, located in Gulf County, Fla., in this area. The maximum projected thickness of the Upper Floridan, however, is in southwestern Florida in the area underlain by middle confining unit VI.

The Floridan aquifer system is youngest in Florida's western panhandle (fig. 9) and in contiguous parts of southern Alabama. Here, the rocks that make up the Upper Floridan aquifer are mostly Oligocene (Chickasawhay Formation) in age and in places include lower Miocene strata (Tampa Limestone). The middle confining unit in this part of the study area, in contrast with the other units mapped on plate 29, corresponds to a single geologic unit—the Bucatunna Formation of Oligocene age. The Bucatunna Formation, mapped as unit V on plate 29, is a massive, dark gray, calcareous soft clay that contains up to 40 percent sand as dis-

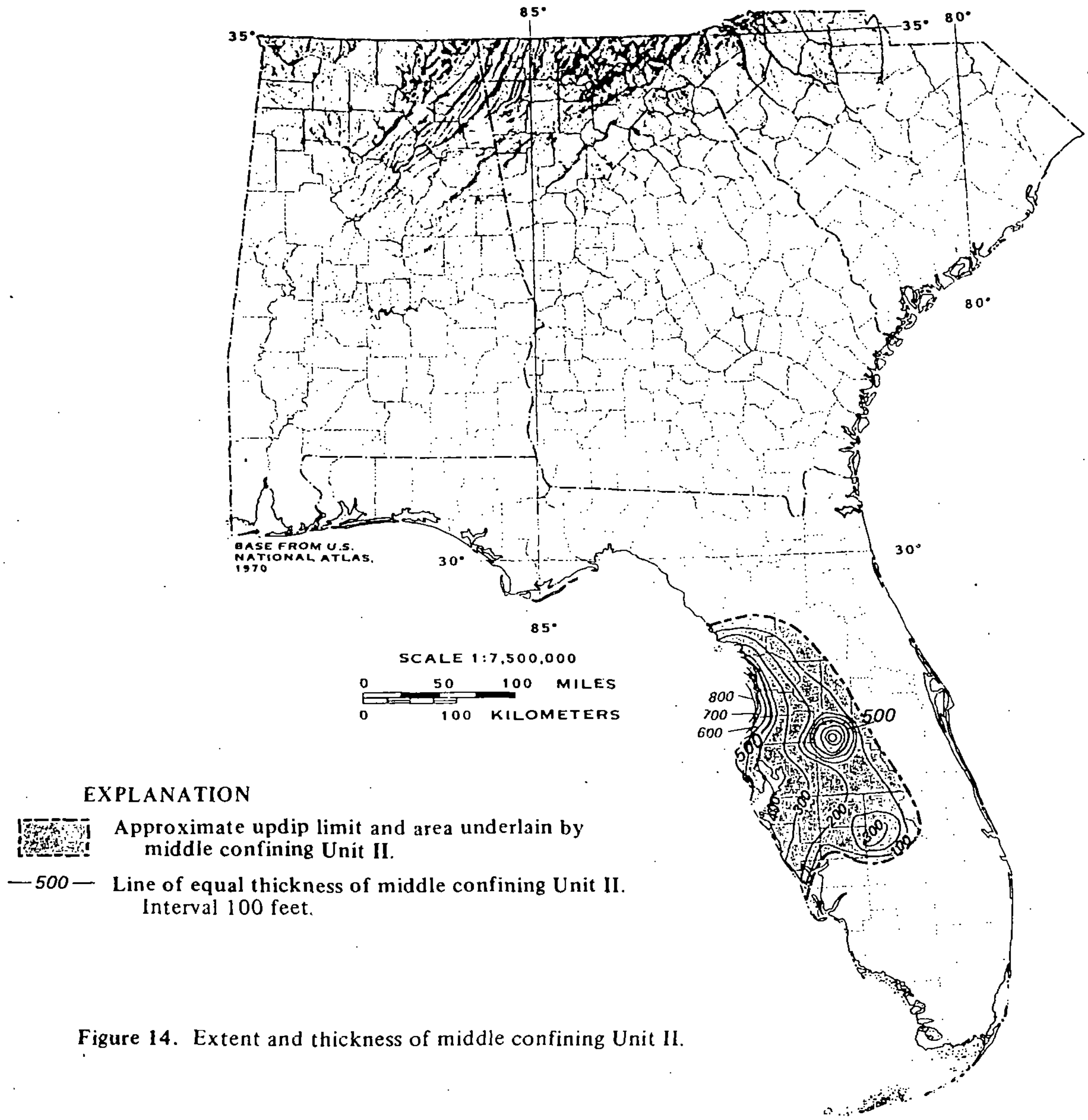
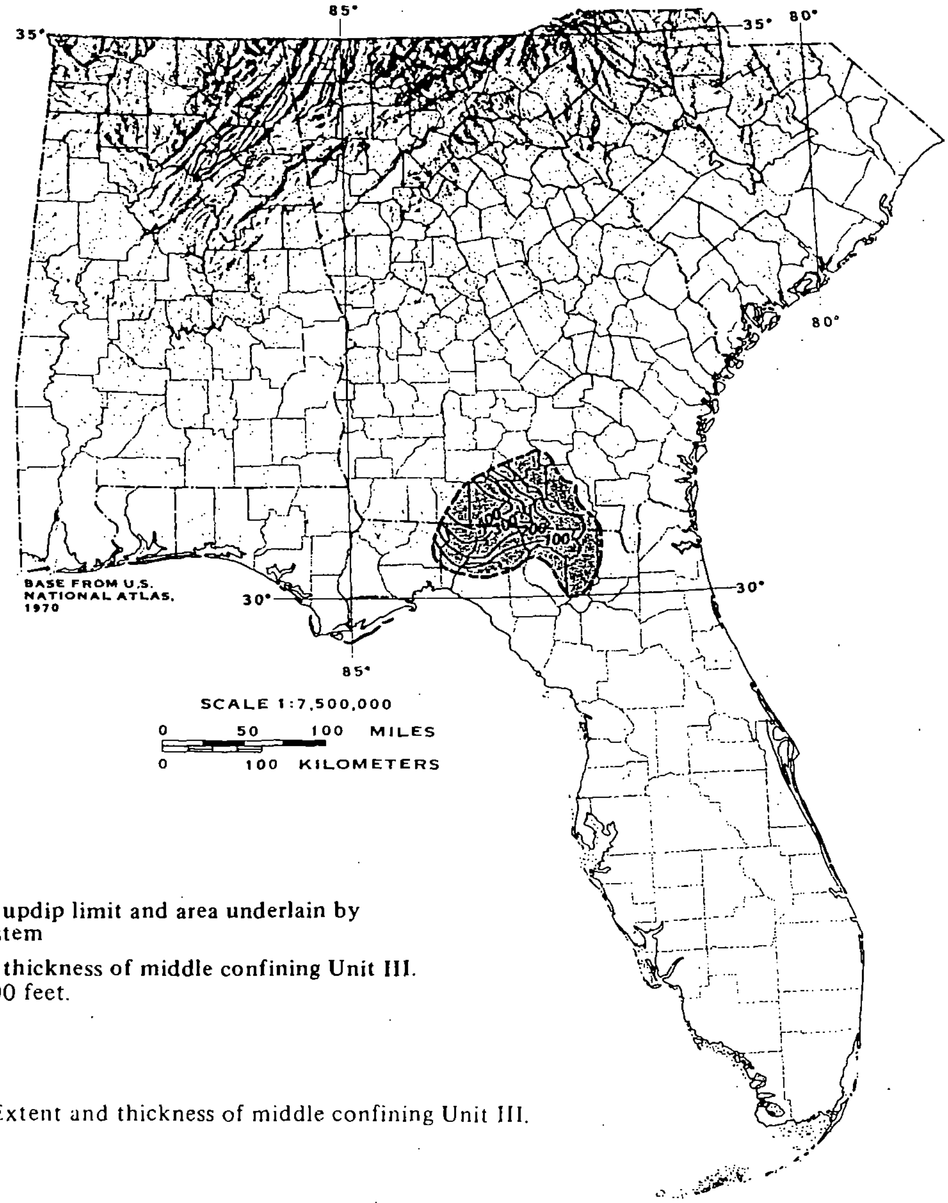


Figure 14. Extent and thickness of middle confining Unit II.

seminated grains and, near its northern and eastern pinchouts, as discrete beds. The thickness of the Bucatunna (fig. 18) is more uniform than that of most of the other middle confining units. The Bucatunna Formation can be readily identified on electric logs because of its extremely low resistivity, and it has been mapped primarily on the basis of this distinctive log pattern. The Lower Floridan aquifer underlies the Bucatunna (unit V) everywhere. Unit V is a virtually nonleaky confining unit. Hydraulic head data from southern Okaloosa County, Fla. (L. R. Hayes, personal commun., 1982), show that the Bucatunna Formation effectively isolates the Upper and Lower Floridan aquifers there. The faults shown in western Alabama on plate 29 disrupt the lateral continuity of unit V in the same manner that they affect the aquifer system permeable zones—downdropping the grabens bounde by the faults has juxtaposed rocks of contrastin permeability.

The rocks that form the base of the Upper Florida aquifer in southwestern peninsular Florida (midd confining unit VI, pl. 29) are a sequence of interbedd finely to coarsely crystalline dolomite and finely pelle al, micritic limestone that is commonly argillaceou The extent of unit VI is shown in figure 19. Ov approximately the western half of the area underla by unit VI, much of the intergranular pore space in t rocks assigned to the unit is filled with gypsum, whi also occurs rarely as thin beds and coarse pods. T thickness of unit VI is shown in figure 20. Unit VI



EXPLANATION

Approximate updip limit and area underlain by aquifer system

—300— Line of equal thickness of middle confining Unit III. Interval 100 feet.

Figure 15. Extent and thickness of middle confining Unit III.

usually found in the lower part of rocks of middle Eocene age, but in places it extends downward to include the upper part of rocks of early Eocene age (see figs. 9, 21). In northern Charlotte County and southern DeSoto and Highlands Counties, Fla., unit VI extends under middle confining unit II, as the dashed contact line on plate 29 shows . Southward, in Dade County and most of Monroe County, Fla., and eastward, in Broward County and part of Palm Beach County, Fla., unit VI is overlapped by unit I (see pl. 29). In both areas, unit VI is separated from the shallower low-permeability unit by a thin to moderately thick sequence of permeable rock. Because of sparse well control, the extent of the overlap shown on plate 29 is approximate. In those places where no shallower confining units overlap unit VI, the Upper Floridan aquifer is considerably thicker than it is where overlap occurs. No hydraulic head data are available across middle confining unit VI, but the unit is considered to be an effective confining bed because of its lithologic character.

A narrow northeast-trending strip of low-permeability rocks in west-central Georgia (middle confining unit VII, pl. 29) marks the base of the Upper Floridan aquifer there. Unit VII partly borders on and in places is gradational into unit III (fig. 16). The rocks that constitute unit VII are micritic to finely crystalline limestone that is often partially dolomitized and contains lenses, pods, beds, and intergranular pore fillings of gypsum. Figure 22 shows the extent and thickness

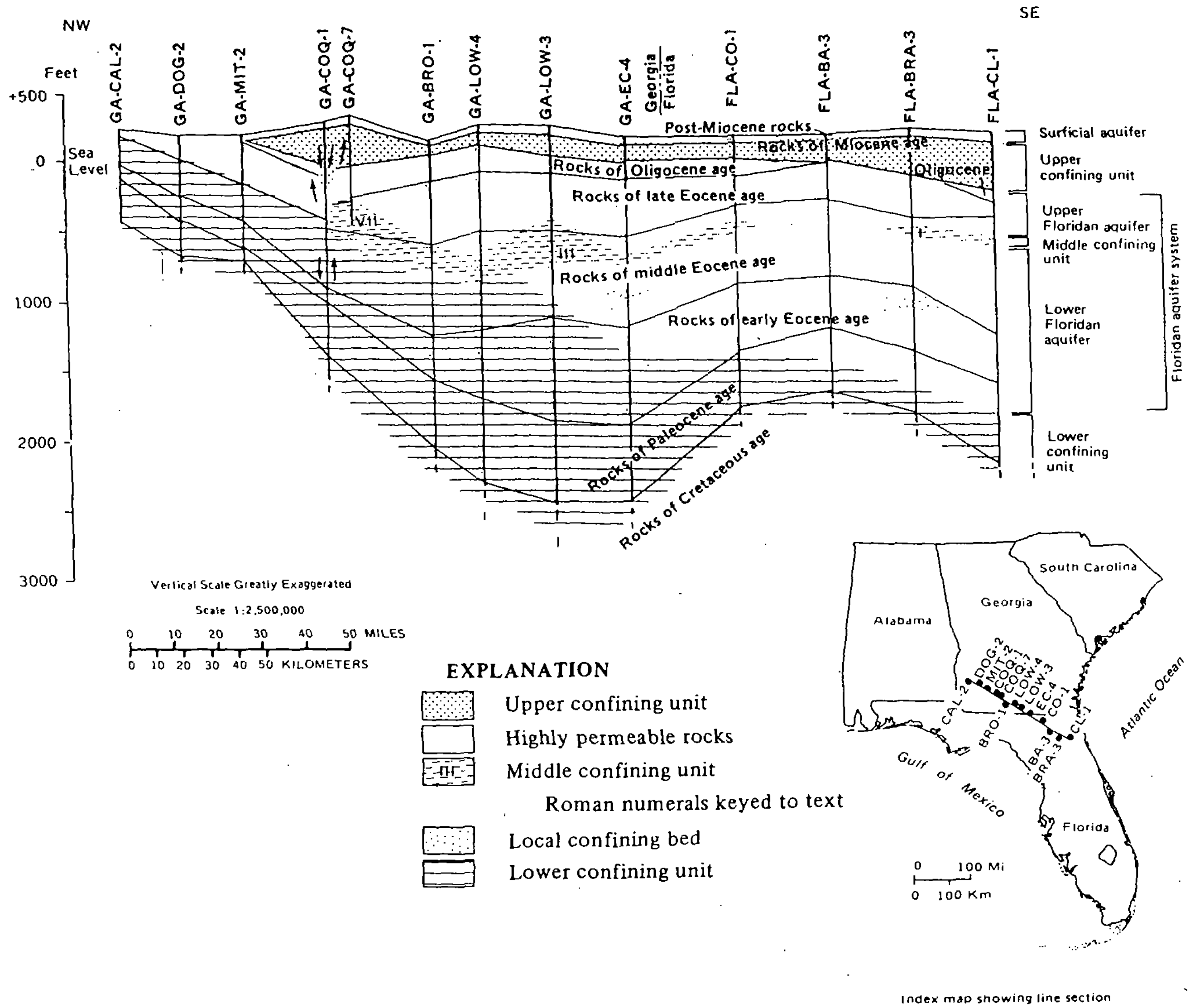
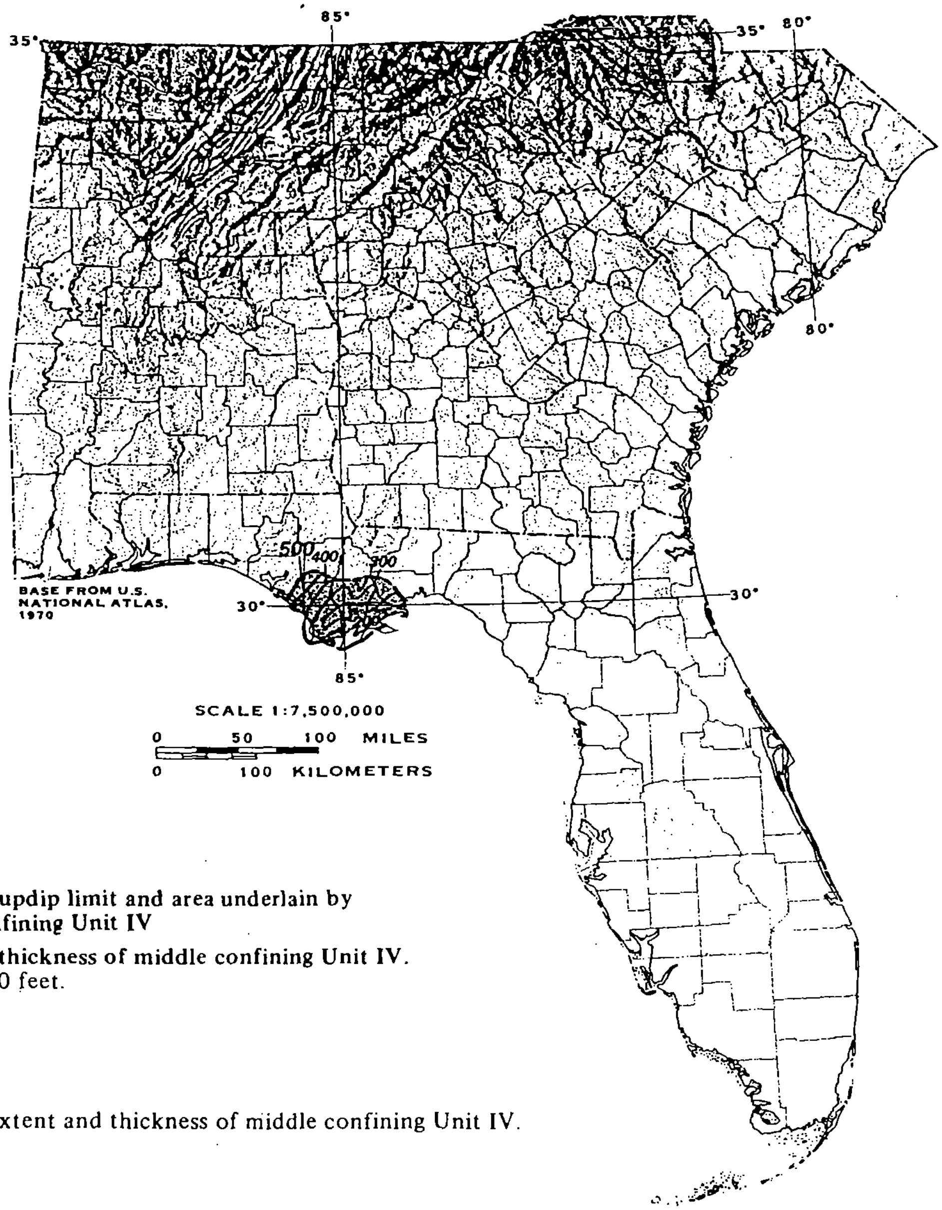


Figure 16. Generalized geohydrologic cross section from Calhoun County, Ga. to Clay County, Fla.

of unit VII. Near its southwestern border, the unit lies in the upper part of rocks of middle Eocene age; in its central part, it is composed of rocks of middle and late Eocene age; toward its northeastern limit, it is restricted to rocks of late Eocene age. Over the southern two-thirds of its extent, middle confining unit VII grades vertically downward into calcareous, glauconitic clastic rocks that are part of the Floridan aquifer system's lower confining unit. In this area, the Lower Floridan aquifer is absent. Farther northward, as the low-permeability rocks of unit VII thin and become younger, the unit is underlain by permeable limestone that is part of the Lower Floridan. The extent of the Lower Floridan aquifer under unit VII is only approximately known because of sparse well control. Unit VII is contiguous with, and just southeast of the Gulf Trough graben system. This author suggests that unit VII exists because it is adjacent to this structural feature. Juxtaposition of low-permeability rocks in the grabens opposite permeable limestone to the northwest (fig. 16) creates a damming effect on groundwater flow through the Floridan aquifer system, as described earlier. The restricted flow downgradient of the Gulf Trough (to the southeast) was not sufficient to dissolve the gypsum from the rocks of unit VII. To the northeast and southwest of the mapped extent of unit VII, either the faults that bound the Gulf Trough are discontinuous or the throw on them is not great. In



EXPLANATION

Approximate updip limit and area underlain by middle confining Unit IV

—200— Line of equal thickness of middle confining Unit IV. Interval 100 feet.

Figure 17. Extent and thickness of middle confining Unit IV.

these places, the rocks equivalent to unit VII are not gypsiferous, possibly because a more vigorous flow system has removed the gypsum by dissolution. On the basis of its lithology, unit VII is thought to be an effective confining unit, but hydraulic head data to quantify its effectiveness are lacking.

Lower Floridan Aquifer

All beds in the Floridan aquifer system that lie below the base of one of the middle confining units and above the base of the aquifer system are included in the Lower Floridan aquifer. Because it is deeply buried and in many places contains poor-quality water, the Lower Floridan has not been intensively drilled or tested, and its hydraulic character is therefore not well known. Scattered hydraulic data show large to small head differences between the Upper and Lower Floridan aquifers. The magnitude of these differences is directly related to the character of the middle confining unit that separates the aquifers; greater differences are found where the confining unit is virtually nonleaky. Ground-water flow in the Lower Floridan aquifer is sluggish except in those places where it is directly connected to the Upper Floridan aquifer. In the regional model discussed by Bush and Johnston (1985), active regional ground-water flow is thought to

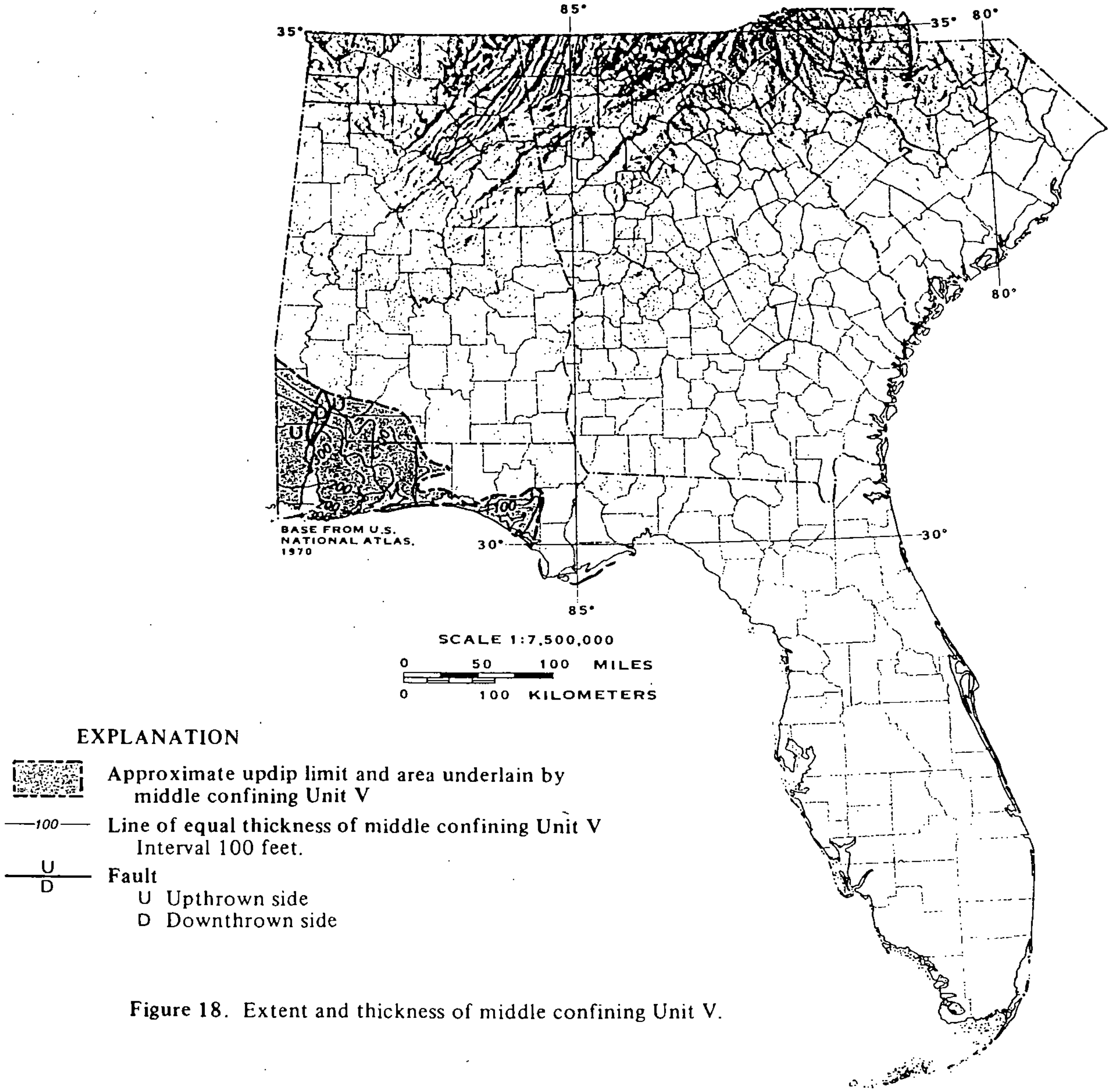
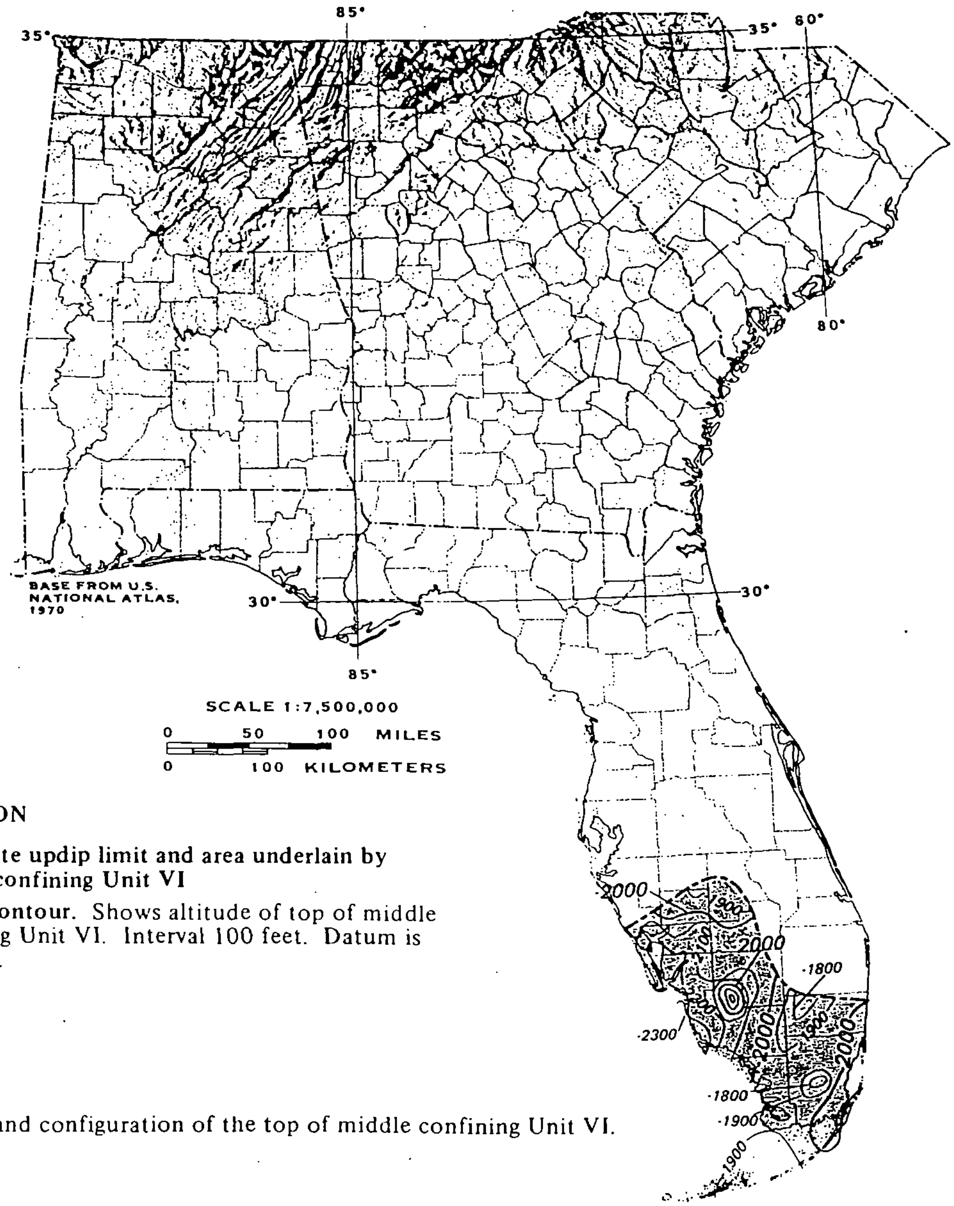


Figure 18. Extent and thickness of middle confining Unit V.

occur in the Lower Floridan aquifer. However, where the Lower Floridan lies below confining beds that are practically nonleaky, it is isolated from the Upper Floridan; and, throughout all of the area treated in the subregional model of Ryder (1985) and part of the area treated by Krause and Randolph (1985), the Lower Floridan is not considered part of the freshwater flow system.

The altitude of the top of the Lower Floridan aquifer is shown on plate 31. Because the top of the Lower Floridan is defined as the base of the highest subregional middle confining unit (units I - III) and because the stratigraphic positions, altitudes, and thicknesses of the confining units vary considerably, the contours shown on plate 31 are drawn on several different horizons. The contact lines shown on the plate mark the approximate limits of the different middle confining units. Where the confining units overlap, as they do in central and southern Florida, the base of the higher unit is contoured, and the extent of the overlap is shown by overlapping contact lines. The Lower Floridan aquifer is not mapped where no middle confining unit exists. In these places, the Lower Floridan merges with and is mapped as part of the Upper Floridan aquifer. The thickness of the Lower Floridan aquifer is mapped on plate 32.

The character of the Lower Floridan aquifer varies from simple (as it is in much of panhandle Florida, where it consists of a thin, fairly uniform sequence of upper Eocene limestone (fig. 9)), to highly complex (as



EXPLANATION

Approximate updip limit and area underlain by middle confining Unit VI

—-2000— Structure contour. Shows altitude of top of middle confining Unit VI. Interval 100 feet. Datum is sea level.

Figure 19. Extent and configuration of the top of middle confining Unit VI.

it is in southern Florida, where it consists of a thick sequence of largely low-permeability rocks separated by relatively thin permeable zones (fig. 21)). For the most part, the rocks comprising the Lower Floridan range from late Paleocene to early middle Eocene age (fig. 9); locally, however, the aquifer may include rocks as young as late Eocene or as old as Late Cretaceous. Some of the thick low- and high-permeability subzones within the Lower Floridan are of subregional extent and have been mapped as a part of this study. These subzones are of interest partly because they represent potential waste-storage receiving or confining beds (southern Florida) and partly because they are in places (for example, extreme northeastern Florida and southeastern Georgia) the source of brackish or saline water that has moved upward and contaminated shallower freshwater-bearing strata (Krause and Randolph, 1985).

A subzone of rocks exhibiting extremely high transmissivity lies deep within the Lower Floridan aquifer in southern Florida. These rocks are mostly massively bedded dolomite within which cavernous permeability is extensively developed. The cavernous and in places fractured nature of the dolomite commonly causes chunks of dolomite to be dislodged during the drilling process, and circulation of drilling fluid is usually lost because of the large-scale porosity and high permeability of the dolomite. The difficult, slow drilling of the dolomite is expressed as a rough bit action, similar to that which occurs in the drilling of boulders. This

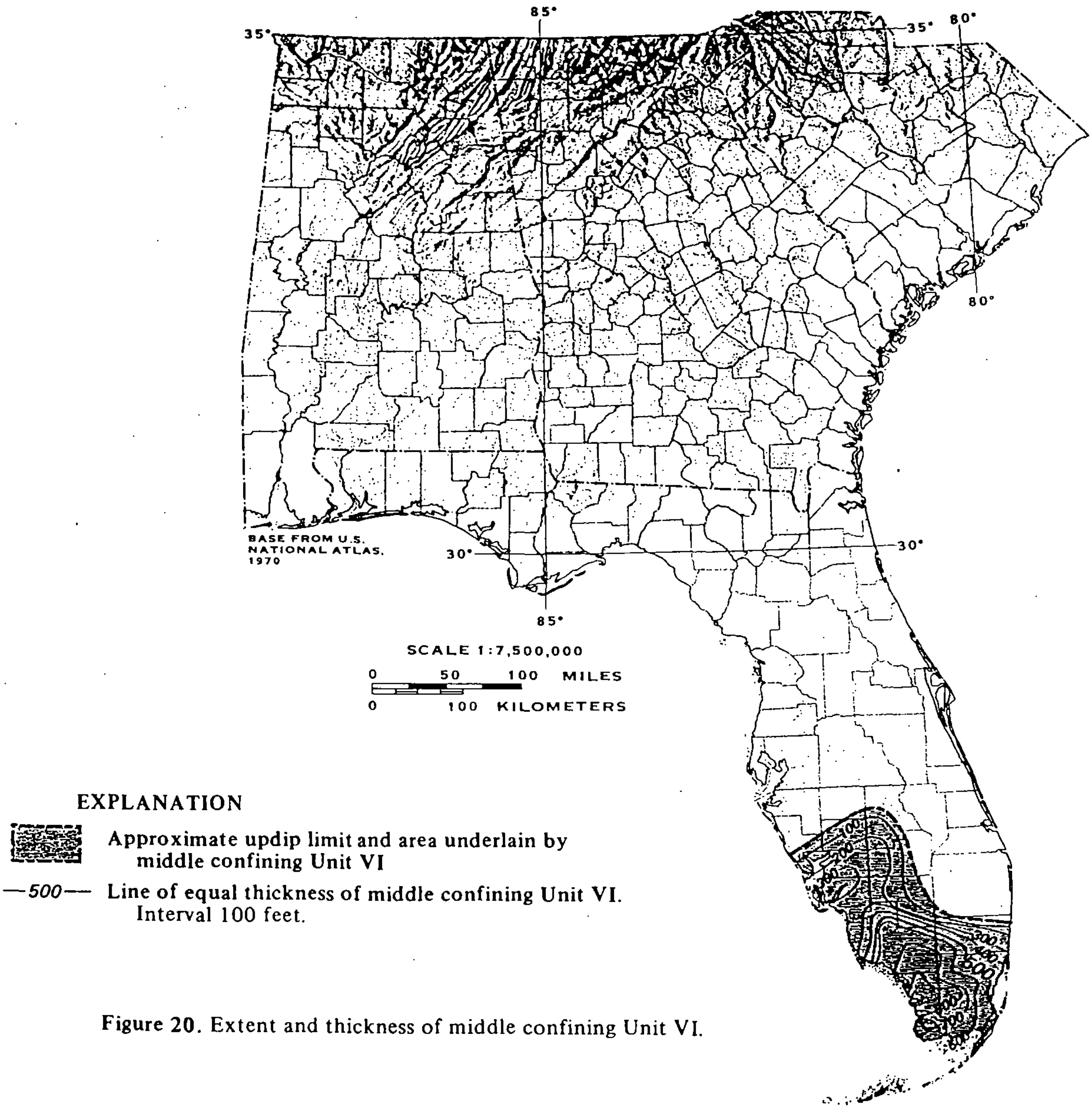


Figure 20. Extent and thickness of middle confining Unit VI.

behavior gave rise to the term "Boulder Zone," first applied to the cavernous dolomite by drillers and subsequently adopted by Kohout (1965) and later authors. The term Boulder Zone is a misnomer because no boulders are present (other than the large chunks occasionally broken off cavern roofs by the drill bit), and the cavernous dolomite is not confined to a single discrete zone. Thus, a "boulder zone" has no stratigraphic significance, because such cavernous conditions can exist at any altitude. The large solution features merely record a period when paleowater tables were at a level that permitted karstification of the upper part of the carbonate rock sequence. Once developed, the karst features can be buried at considerable depth, as they have been in southern Florida's Boulder Zone.

A "boulder zone" does not represent a single cavernous horizon developed over a wide area at the same depth or at the same stratigraphic position. Rather, such a zone represents a fairly thick horizon of large-scale solution-produced openings that are developed, like modern cave systems, primarily parallel to bedding planes at several different levels over a vertical span that may reach several hundred feet. Borehole televiewer surveys show that these levels, separated by intervals of undissolved rock, are commonly connected by vertical fractures. If these fractures are enlarged by dissolution, vertical "pipes" are developed

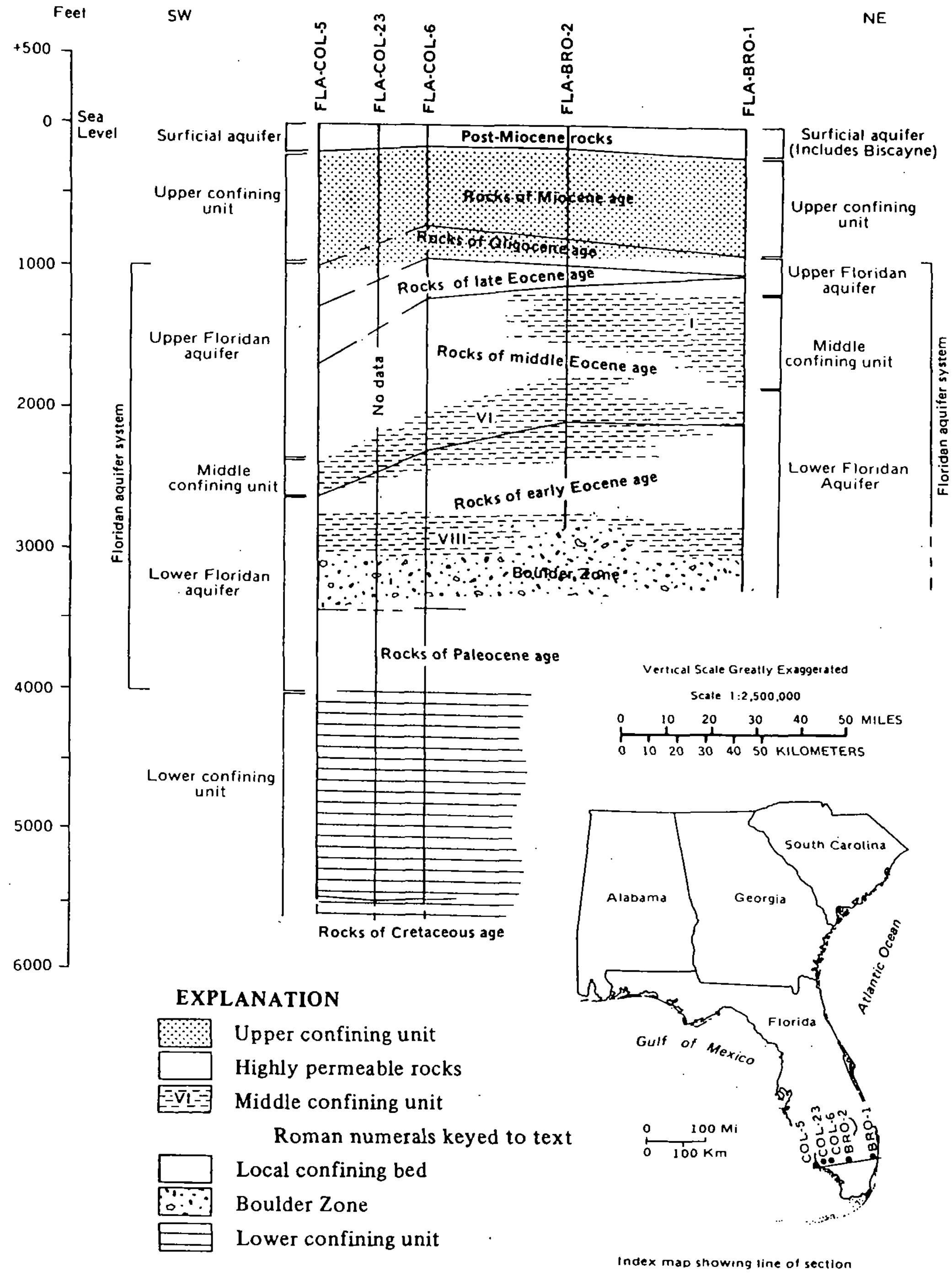
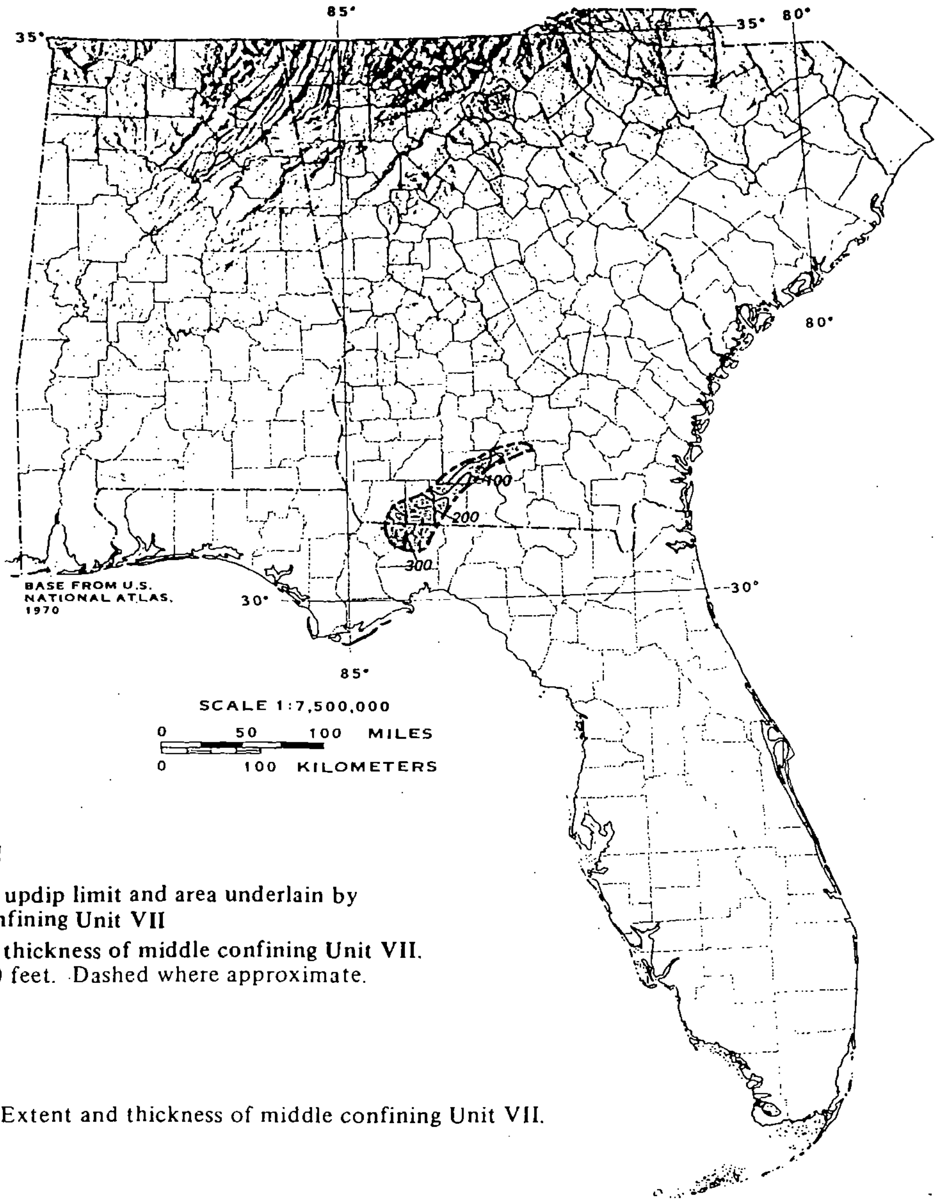


Figure 21. Generalized geohydrologic cross section from western Collier to eastern Broward Counties, Fla.

that connect the horizontal cavernous levels. The 90-ft- high "cavern" reported by Kohout (1965, p. 262) in his discussion of the Boulder Zone is thought by this author to represent such a pipe rather than a large "room" in a cavern system.

Even though a "boulder zone" is not everywhere laterally continuous and may extend vertically across stratigraphic horizons, the zone can be used hydrologically in an informal "operational unit" sense. For example, in southern Florida, one can reasonably ex-



EXPLANATION

Approximate updip limit and area underlain by middle confining Unit VII

—300— Line of equal thickness of middle confining Unit VII. Interval 50 feet. Dashed where approximate.

Figure 22. Extent and thickness of middle confining Unit VII.

pect to encounter a high-permeability, commonly cavernous zone at depths of about 2,500 to 3,000 ft. The Boulder Zone of the literature (Kohout, 1965) usually occurs in the bottom third of the lower Eocene Oldsmar Formation, about 100 to 150 ft above the top of Paleocene rocks. Locally, the Boulder Zone may range upward to the middle of the Oldsmar or downward to the top of the Paleocene Cedar Keys Formation. In this report, the Boulder Zone is considered to be a widespread high-permeability unit, and the extent and configuration of the top of the zone are shown in figure 23. The Boulder Zone loses its cavernous character northward and merges with permeable strata that are part of the Lower Floridan aquifer (see pls. 17, 30). Temperature and salinity data from Boulder Zone waters, supplemented by scattered hydraulic head data, indicate that the Boulder Zone is connected to the modern ocean in the Straits of Florida and that there is inland flow of water in the zone (F. W. Meyer, written commun., 1984). The permeability of the Boulder Zone is extremely high owing to its cavernous nature. An analysis of cyclic natural water-level fluctuations in a partially penetrating well (Meyer, 1974) yielded a transmissivity of 3.2×10^6 ft^2/d for only the upper 20 ft of the zone. The transmissivity of the entire thickness of the Boulder Zone probably exceeds 10^7 ft^2/d. The Boulder Zone contains saline water everywhere and is extensively used along Florida's southeastern coast as a receiving zone for treated municipal liquid wastes.

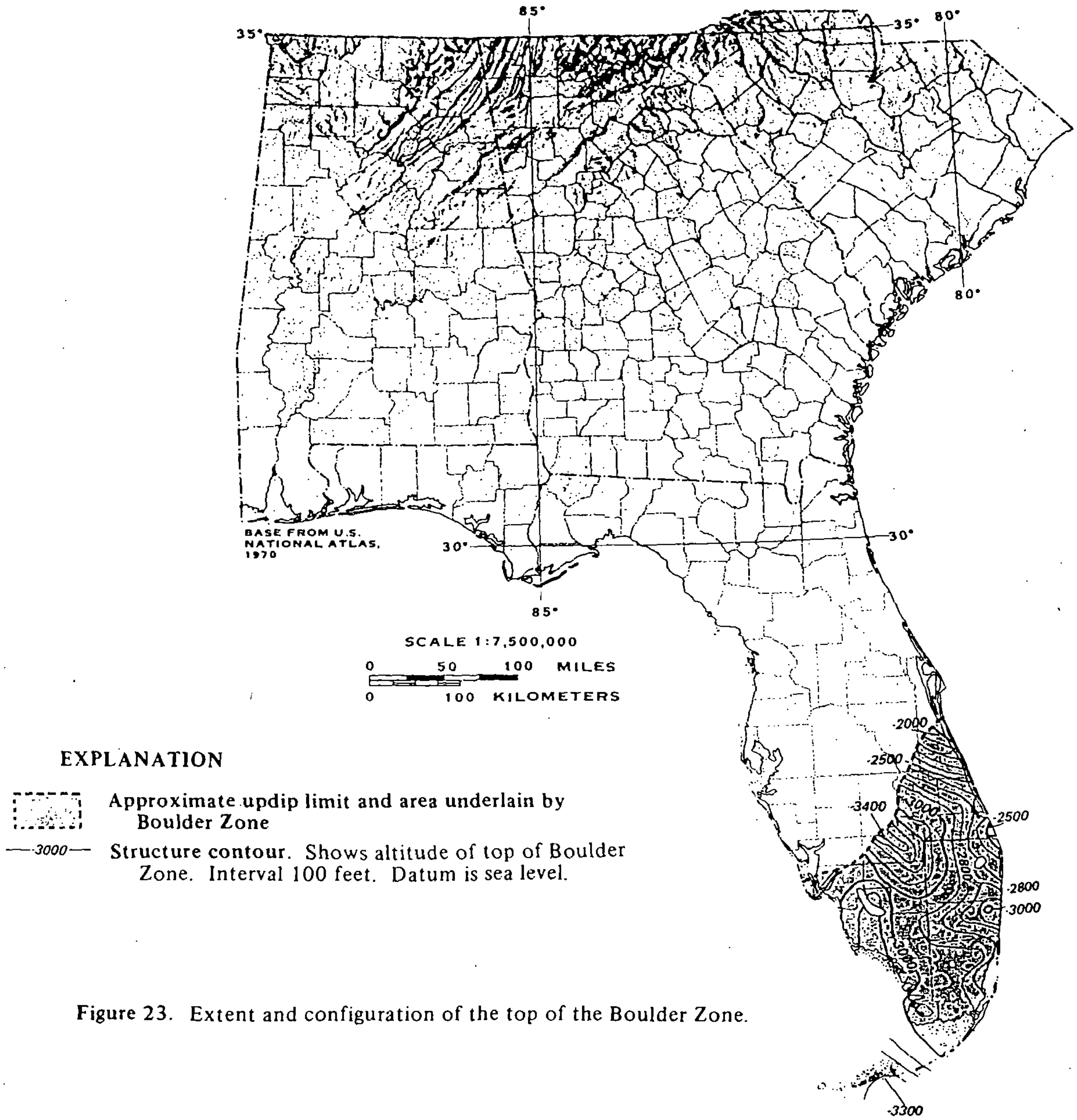


Figure 23. Extent and configuration of the top of the Boulder Zone.

A second high-permeability zone that is cavernous in part lies above the Boulder Zone and occurs in the lower part of rocks of middle Eocene age. In general, this shallower zone is found north of the Boulder Zone and in places overlaps it (Miller, 1979). Unlike the Boulder Zone, the middle Eocene cavernous interval commonly contains freshwater. Locally, as many as eight separate cavernous levels have been penetrated in the same borehole (Vernon, 1970, p. 10). Only the middle Eocene cavernous interval and the Boulder Zone are areally extensive, however, and only the Boulder Zone has been mapped for this study; the middle Eocene cavernous interval is not separated from the other permeable strata in the Lower Floridan aquifer. Neither cavernous zone appears to be consistently related to rock type or texture, dolomite percentage, thickness of the stratigraphic unit containing the zone, or location of chert, anhydrite, or peat beds. The shallower cavernous interval shows high permeability where middle Eocene rocks are structurally high, as one would expect if the zone were produced by karst activity. The Boulder Zone, however, shows no such relationship.

A thick middle confining unit that is regionally included in the Lower Floridan aquifer overlies and extends beyond the Boulder Zone (pls. 17, 30). This unit occurs in the middle part of rocks of early Eocene age and consists mostly of micritic to finely pelletal limestone and lesser amounts of interbedded, finely crystalline dolomite. The extent and configuration of

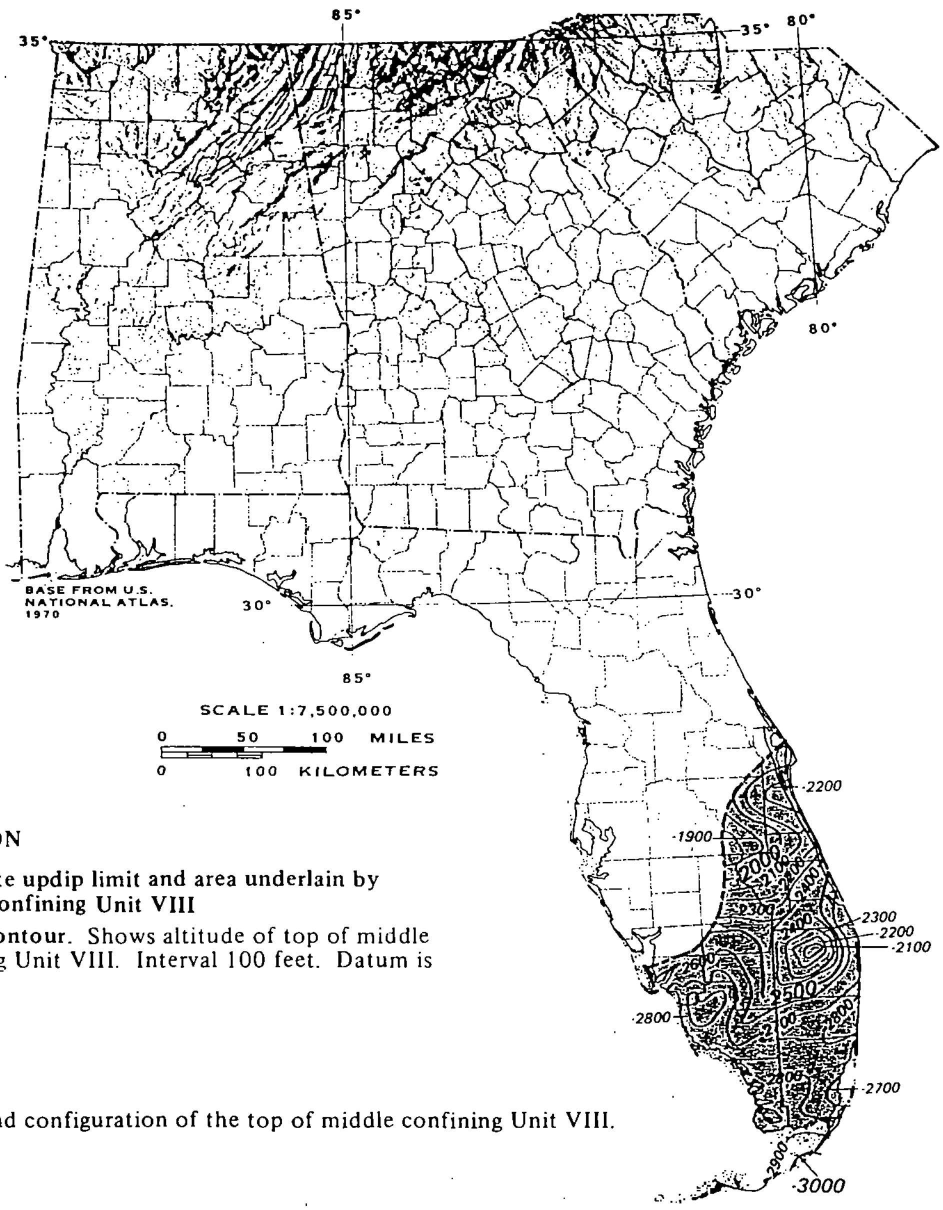


Figure 24. Extent and configuration of the top of middle confining Unit VIII.

the top of this confining unit are shown in figure 24. The unit is designated middle confining unit VIII, and its relation to the Boulder Zone is shown on plate 30. The thickness of the unit is shown in figure 25. Test drilling done for this study shows that thin local beds of dolomite within this confining unit have high permeability, but the overall permeability of unit VIII is low. Data from several deep test and injection wells along Florida's southeastern coast, some areas of which use the Boulder Zone as a receiving zone for treated municipal liquid wastes, show that unit VIII is an effective confining unit there.

Little is known about unit VIII in southwestern Florida, but scattered data from oil test wells indicate that it is an effective confining unit. To the north and west, unit VIII grades laterally into permeable beds that are part of the Lower Floridan aquifer (pl. 17).

A high-permeability unit of subregional extent lies at the base of the Lower Floridan aquifer in parts of southeastern Georgia and northeastern Florida. This unit is given the informal designation "Fernandina permeable zone" in this report because it is best known in the Fernandina Beach area of easternmost Duval County, Fla. The extent and configuration of the top of the Fernandina permeable zone are shown in figure 26. The zone consists of coarsely pelletal, vuggy limestone that is commonly dolomitized and locally cavernous in its upper part. For the most part, the zone is

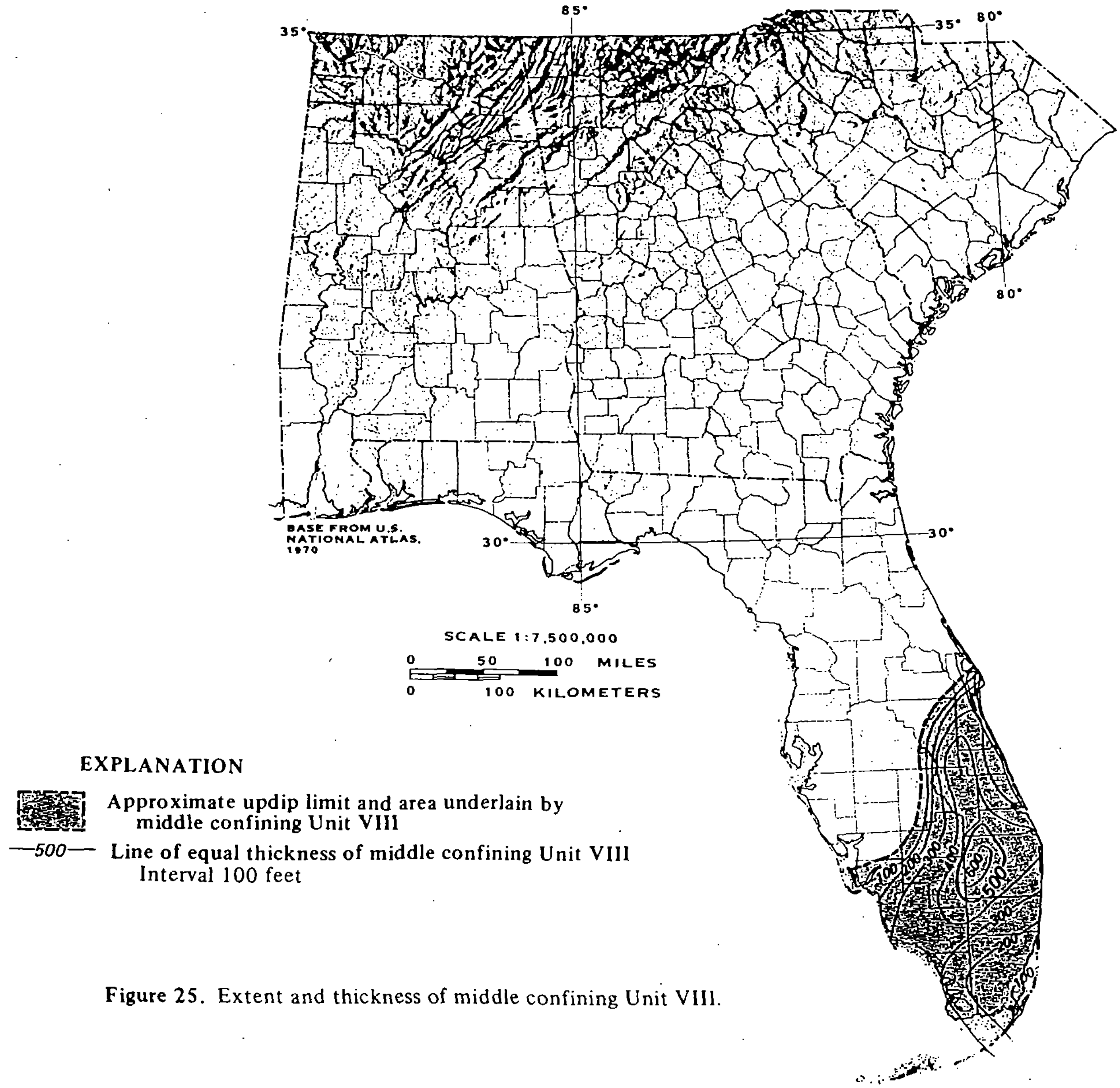
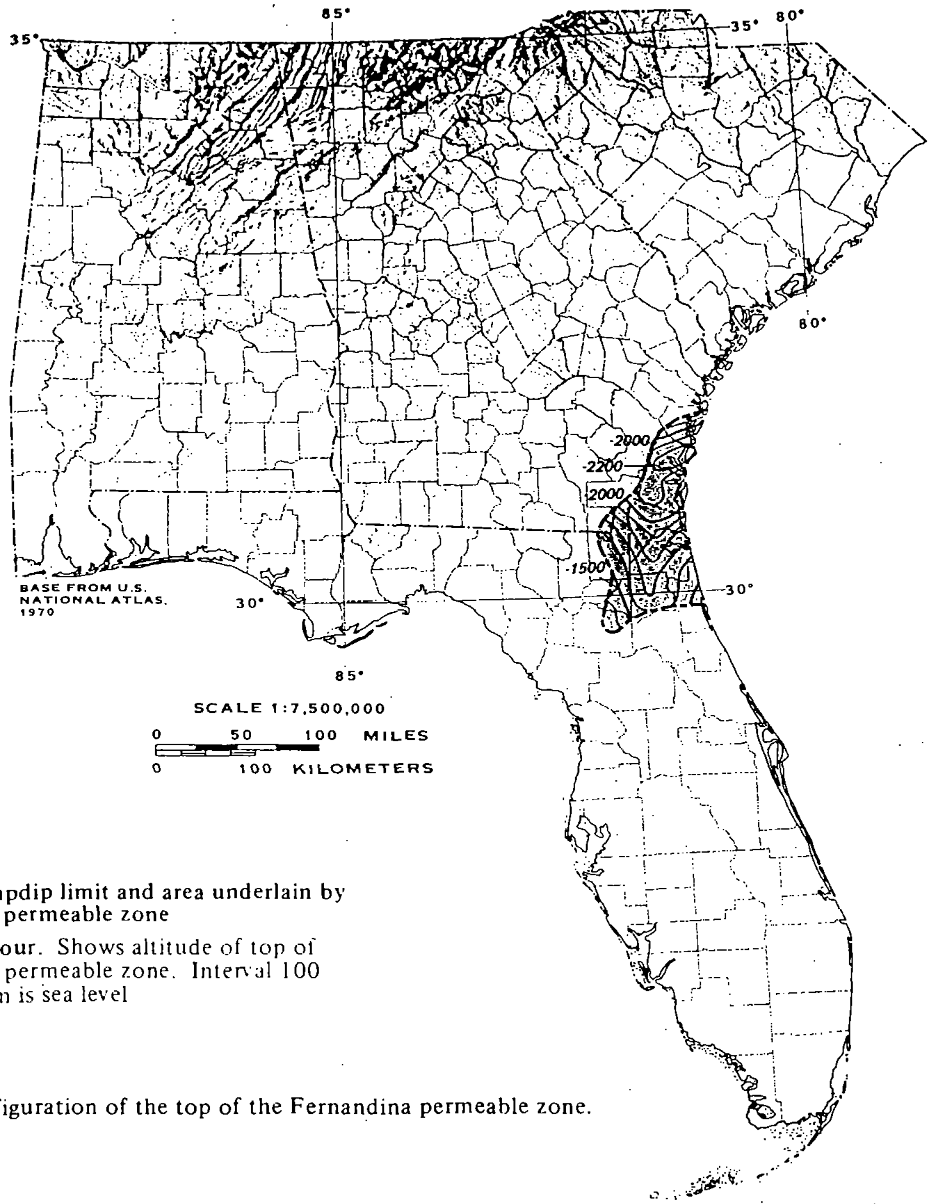


Figure 25. Extent and thickness of middle confining Unit VIII.

restricted to rocks of late Paleocene age, but in places it includes rocks as young as early Eocene or as old as Late Cretaceous (fig. 12). The Fernandina permeable zone is overlain by a confining unit composed of microcrystalline, locally gypsiferous dolomite and finely pelletal micritic limestone that in most places effectively separates the zone from shallower permeable strata. In the Brunswick, Ga., area, however, unpublished data from a deep test well (H. E. Gill, oral commun., 1982) show that this confining unit is fractured and that the fractures provide conduits that have allowed saline water from the Fernandina permeable zone to move upward in response to heavy pumping from the Upper Floridan aquifer and thereby contaminate the shallower permeable zones. The confining unit pinches out in Florida to the south and southwest, and the Fernandina zone merges with shallower permeable strata (fig. 12). To the north and west in Georgia, the confining unit is shown in figure 12 to be a tongue of low-permeability material that extends downdip into permeable strata from the aquifer's lower confining unit. Locally, water in the uppermost part of the Fernandina permeable zone is fresh (Leve and Goolsby, 1967; Brown, 1980), but the high salinity of the water that the zone contains in most places shows that ground-water flow in the zone is very sluggish. Simulation (Krause and Randolph, 1985) shows that the Fernandina zone is part of the Floridan aquifer



EXPLANATION

Approximate updip limit and area underlain by Fernandina permeable zone

—1500— Structure contour. Shows altitude of top of Fernandina permeable zone. Interval 100 feet. Datum is sea level

Figure 26. Extent and configuration of the top of the Fernandina permeable zone.

system's regional flow network, however. Although the Fernandina zone is locally cavernous, it is in no way connected with or related to south Florida's Boulder Zone. The Fernandina permeable zone is included as a subunit of the Lower Floridan aquifer (fig. 8).

LOWER CONFINING UNIT

The rocks that comprise the Floridan aquifer system's lower confining unit are generally of two types: either glauconitic, calcareous, argillaceous to arenaceous strata that range in age from late Eocene to late Paleocene or massively bedded anhydrite that usually occurs in the lower two-thirds of rocks of Paleocene age. Locally, in the Mobile Graben and just to the northwest of it in western Alabama, the Lower Floridan aquifer is not present, and the Bucatunna Formation that comprises middle confining unit V elsewhere forms the base of the aquifer system. The permeability of the rocks comprising the aquifer system's base is everywhere much less than that of the carbonate rocks that lie above them. Like the top of the aquifer system, its base is defined in terms of a permeability contrast and does not conform to the same geologic horizon or rock type everywhere. The altitude and configuration of the base of the aquifer system (top of its lower confining unit) as shown on plate 33, modified from a map by Miller (1982c), thus represent a composite surface that crosses formation

and time boundaries. The base of the Floridan aquifer system does not crop out, and the areal extent and lithologic character of the different units delineated on plate 33 were determined solely from well control. Low-permeability clastic rocks that are the stratigraphic equivalents of the aquifer system's base do, in fact, crop out updip from the limit of the aquifer system. Where the aquifer system itself is not present, however, it is meaningless to map these low-permeability rocks as the system's base. The altitude of the base of the aquifer system may differ locally from that shown, particularly in areas of sparse well control. Although the different units shown in updip areas extend north and west of the line that marks the aquifer's approximate updip extent, they have not been mapped past the limit of the aquifer. It is important to stress that the contours shown on plate 33 generally do not represent the top of a particular time-stratigraphic unit; rather, they show the top of a permeability contrast that usually occurs within such a unit. Below the altitudes shown, there is no high-permeability carbonate rock. The different time-stratigraphic units that comprise the aquifer system's base, as shown on plate 33, are described in order below, from youngest to oldest. In general, the base of the aquifer system is marked by progressively older rocks in a downdip direction because depositional environments become progressively more marine and thereby more favorable for the accumulation of a thicker sequence of permeable limestone in a seaward direction.

ROCKS OF LATE EOCENE AGE

In western panhandle Florida and southern Alabama, the Floridan aquifer system's lower confining unit consists of interbedded glauconitic, calcareous sand and sandy clay of late Eocene (Jacksonian) age. These rocks lie immediately under the Ocala Limestone. Although detailed correlation has not been done between these calcareous clastic rocks and outcropping upper Eocene rocks, they are thought to be equivalent to the Moodys Branch Formation of western Alabama. In Geneva and Houston Counties in southeastern Alabama (pl. 33), the small area of upper Eocene rocks that comprises the base of the aquifer is also thought to be equivalent to the Moodys Branch. The upper Eocene strata in this small area are glauconitic, calcareous clastic rocks, lithologically similar to the outcropping Moodys Branch. In the northeastern part of the Georgia coastal plain, upper Eocene rocks that consist of fossiliferous, slightly sandy and glauconitic, calcareous clay mark the base of the aquifer system. These rocks are equivalent to the Eocene part of the Cooper Formation (formerly called the Cooper Marl), a low-permeability unit that is in part of late Eocene and in part of Oligocene age (pl. 2). In south-central Georgia, a small, roughly oval patch of upper Eocene rocks makes up the base of the aquifer system (pl. 33). These strata are adjacent to and just down the hydraulic gradient from a series of small faults that bound narrow grabens. The rocks, which are part of the Ocala Limestone, consist primarily of bryozoan particles and whole to broken large Foraminifera loosely bound by a micrite matrix. Here, however, gypsum has filled most of the pore space in the normally highly permeable Ocala. The gypsum has not been dissolved, probably because movement along the faults has downdropped low-permeability clastic rocks that fill the grabens opposite high-permeability limestone to the northwest and thereby created a damming effect on ground-water flow within the Floridan aquifer system. The restricted flow southeast of the faulted area has not been sufficient to remove the pore-filling gypsum from the Ocala. These low-permeability Ocala beds grade downward into glauconitic clastic rocks of middle Eocene age, with no permeable limestone between the clastic and gypsum-rich strata.

ROCKS OF MIDDLE EOCENE AGE

Adjacent to the updip limit of the Floridan aquifer system in southwestern Georgia and much of southeastern Alabama and for a considerable distance downdip of these areas (pl. 33), the aquifer system's lower confining unit consists of fine-grained, calcareous, glauconitic sand interbedded with gray to greenish-gray clay and clayey sand. These clastic strata are of middle Eocene (Claibornian) age and are thought to be equivalent to the outcropping Lisbon Formation (upper part of the middle Eocene). Farther downdip, as the amount of permeable limestone in the Tertiary section increases, the aquifer system thickens rapidly, and its base becomes progressively lower to the southeast with respect to both altitude and stratigraphic position. In a narrow, irregular, northeast-trending strip across the central Georgia coastal plain (pl. 33), the clastic rocks that are Lisbon equivalents grade by facies change into permeable limestone. Here the aquifer system's lower confining unit consists of highly glauconitic, fine-grained, greenish-gray sand interbedded with green to brown clay or clayey sand, all equivalent to the Tallahatta Formation of outcrop (lower part of the middle Eocene). In the central and east-central parts of panhandle Florida, the amount of permeable limestone in the aquifer system thickens toward the Gulf of Mexico, and the system's base becomes stratigraphically lower, as it does in Georgia. In the panhandle area, however, there is no lithologic

or paleontologic difference between the upper and lower parts of the middle Eocene section. The glauconitic, calcareous clastic rocks that mark the base of the aquifer system are accordingly mapped on plate 33 as equivalent to the Lisbon Formation; the Tallahatta equivalent cannot be distinguished. In the area of southwestern South Carolina and northeastern Georgia that is adjacent to the Savannah River (pl. 33), the aquifer system's lower confining unit is comprised of highly sandy, greenish-gray, calcareous clay interbedded with soft, sandy to argillaceous limestone and fine-grained calcareous sand. These rocks are thought to be equivalent to parts of the Santee Limestone of South Carolina. The Lisbon and Tallahatta equivalents together grade laterally northeastward into the Santee by facies change.

ROCKS OF EARLY EOCENE AGE

In a narrow band in eastern panhandle Florida and a slightly wider strip in east-central Georgia, clastic rocks of early Eocene (late Sabinian) age form the Floridan aquifer system's lower confining unit (pl. 33). These rocks, which consist of highly glauconitic, silty, often micaceous, fine-grained sand interbedded with brown lignitic clay, are all of low permeability and are thought to represent in part the equivalents of the Hatchitigbee and Tuscahoma Formations that crop out in Alabama. Like the middle Eocene strata in east-central panhandle Florida, they cannot be differentiated into discrete formations in the subsurface and accordingly are mapped on plate 33 as "undifferentiated rocks of early Eocene age." Finely-crystalline, dark-gray, gypsiferous limestone interfingers with these clastic rocks locally, particularly adjacent to places where the Oldsmar Formation forms the aquifer system's base. The Oldsmar represents a carbonate-bank facies of the undifferentiated lower Eocene clastic rocks. The Oldsmar beds that form the aquifer system's lower confining unit in southcentral Georgia and contiguous parts of northern Florida (pl. 33) are glauconitic, micritic to finely crystalline, gypsiferous, cream, brown, and dark-gray limestone interbedded with dark-brown gypsiferous dolomite. In most of southwestern South Carolina (pl. 33), the base of the aquifer system consists of interbedded gray to black clay, red to brown sandy clay, and fine-grained, white, calcareous sand and clayey sand, all of which are equivalent to the upper part of the Black Mingo Formation.

ROCKS OF PALEOCENE AGE

Throughout most of Franklin County and in southern Gulf and Liberty Counties in Florida's eastern panhandle (pl. 33), the base of the Floridan aquifer system consists of hard, cherty, sandy, finely crystalline limestone thickly interbedded with massive brown to black clay. These rocks are of Paleocene age but have no exact corollary in the outcropping Paleocene rocks of either Georgia or Alabama. Their overall lithology resembles that of the Clayton Formation more closely than that of any other described Paleocene unit, and they are accordingly mapped as questionably equivalent to that formation. Eastward, these rocks grade into an interbedded carbonate-evaporite sequence that is part of the Cedar Keys Formation. Cedar Keys rocks, as plate 33 shows, make up the aquifer system's lower confining unit over practically all of peninsular Florida and over a small area in southeastern Georgia. The Cedar Keys consists mostly of thick-bedded dolomite and dolomitic limestone; massive anhydrite beds occur in the lower two-thirds of the formation. These areally extensive, low-permeability evaporites form a very effective confining bed at the aquifer system's base. The permeable dolomite and dolomitic limestone in the upper part of the Cedar Keys are included in the Floridan aquifer system, however. Accordingly, the drastic permeability decrease that marks the aquifer system's base occurs within the Cedar Keys, not at the formation's top. Anhydrite beds occur locally in younger rocks, especially in the lower Eocene Oldsmar Formation and less commonly in the lower part of rocks of middle Eocene age. The evaporite beds do not make up a regional confining unit in any horizon younger than the Paleocene, however. In the central part of western peninsular Florida, a middle Eocene gypsiferous dolomite unit has previously been mapped as the base of the aquifer system (Wolansky and others, 1979). Although this low-permeability dolomite does constitute an effective confining unit (middle confining unit II of this report), deep well data show that it is underlain by permeable limestone considered in this report to be part of the Lower Floridan aquifer. Accordingly, anhydrite beds of the Cedar Keys Formation, which in turn lie beneath the lower major permeable zone, make up the aquifer system's base here, as they do elsewhere in the Florida peninsula.

ROCKS OF LATE CRETACEOUS AGE

The Floridan aquifer system is very thick in the Brunswick, Ga., area. Test wells in southern Glynn County, Ga., show that rocks of Oligocene age through the upper part of rocks of Late Cretaceous age are part of the aquifer system there. The base of the system lies several hundred feet below the top of the Late Cretaceous and consists of soft, friable limestone of probable Taylor age (pl. 33). These rocks, which lie entirely in

the subsurface, are at present unnamed in both Florida and Georgia. The permeable Cretaceous limestone that overlies the rocks of Taylor age is part of the Lawson Limestone of Navarro age.

CONFIGURATION OF SURFACE

Although the top of the lower confining unit represents a composite of the tops of several low-permeability horizons of different ages and different rock types, some of the large-scale features contoured on plate 33 reflect major structural elements in the eastern Gulf Coast. The east-trending low area centered near Brunswick, Ga., is part of the Southeast Georgia embayment; the negative area in Franklin and Gulf Counties, Fla., represents the Southwest Georgia or Apalachicola embayment; and the low area centered in Lee and Hendry Counties, Fla., is part of the South Florida basin. The steep, steady gulfward slope of the aquifer system's base in western panhandle Florida reflects the influence of the Gulf Coast geosyncline.

The axis of the positive area in northwestern peninsular Florida lies in an intermediate position between the axis of the Peninsular arch and the axis of the "Ocala uplift." This high area probably represents the approximate location of the Peninsular arch or is related to it, even though the axes of the two features do not exactly coincide.

In the broad area in peninsular Florida where anhydrite beds of the Cedar Keys Formation form the base of the aquifer system (pl. 33), the altitude of the highest anhydrite bed has been plotted and then contoured as if the evaporites were everywhere continuous. Actually, they are not. The anhydrite beds probably formed in tidal flat or sabkha environments that were of local extent (P. A. Thayer, personal commun., 1982) and, after burial, now occur as isolated discontinuous lenses that "float" in a mass of carbonate rocks. The lenses are confined, however, to a zone within the middle to lower third of the Cedar Keys, and it is the surface of this evaporite-rich zone that is contoured. Thus, the small, low- to moderate-relief (100 - 300 ft) positive and negative features shown on plate 33 in southern peninsular Florida, rather than being local structural features, represent local evaporite beds that occur at altitudes higher or lower than those of the main body of the Cedar Keys anhydrite-rich zone.

The faults shown in central Georgia on plate 33 are those that bound the series of small grabens called the Gulf Trough. The faults cut the low-permeability rocks that comprise the base of the aquifer system and displace them as shown. Because of the lack of deep well control in and adjacent to the Gulf Trough, the depth to which these faults penetrate is not known. Their geometry, however, indicates that they probably die out at a relatively shallow depth. The faults in southwestern Alabama, which also bound a series of grabens, also cut the base of the aquifer system. Unlike the faults that bound the Gulf Trough, the Alabama faults are known to extend to great depths (Copeland, 1968; Moore, 1971). To the south and west of the Alabama faults, the Floridan aquifer system is very thin and effectively isolated from the main body of limestone because movement along the faults has downdropped relatively impermeable beds opposite the permeable limestone of the aquifer system.

REGIONAL VARIATIONS IN PERMEABILITY

The rocks that make up the Floridan aquifer system are a series of platform carbonate beds that were laid down in warm, shallow water in an environment similar to that of the modern Bahama Banks. The original texture of the limestone ranged from micritic to biosparruditic (textural terms from Folk (1959)) and, like modern carbonates, varied considerably over short lateral distances, depending upon the exact depositional environment at a given place. Slight differences in the depth, temperature, and salinity of ocean waters or in current strength and distribution affect the types and numbers of calcium carbonate-fixing organisms that are present as well as the amount of micrite and the percentage and size of limestone pellets that can accumulate. As the carbonate sediment becomes consolidated, these organic and textural factors determine the primary texture of the limestone formed, which in turn determines the primary porosity and permeability of the rock. For example, the Ocala Limestone, which is part of the Upper Floridan aquifer, was deposited in shallow, warm, clear water and consists in many places of a coquina of bryozoan fragments and large Foraminifera loosely cemented with sparry calcite or a small amount of micrite. The permeability of the Ocala is high nearly everywhere. By contrast, gypsiferous dolomite of middle Eocene age (middle confining unit II) was deposited largely in a series of sabkhas or tidal flats, and has a very low permeability.

Diagenesis subsequent to deposition at any stage of consolidation of the rock can either enhance or decrease limestone permeability. For the Floridan aquifer system, dolomitization has been the chief diagenetic process affecting permeability. Depending upon the original limestone texture, dolomitization can increase or decrease the porosity of the rock. If the original rock is a micrite, it may be recrystallized into a loosely interlocking mosaic of dolomite crystals that is highly porous. On the other hand, if the originally high porosity of a loosely packed, coarsely pelletal limestone is almost completely filled with finely crystalline

dolomite, an effective confining unit is created out of a once-permeable rock. The degree to which the original limestone porosity is affected depends also upon whether dolomitization is partial or complete; if the process is incomplete, some of the original porosity may be preserved. The exact mechanism by which dolomitization took place in the study area is unclear. Some of the observed dolomitization is possibly related to paleo or modern ground-water flow systems (Hanshaw and others, 1971; Hanshaw and Back, 1979). Periodic, perhaps repeated exposure of the limestones and flushing of their interstitial saline waters by freshwater is one mechanism by which the amount of magnesium-rich water required to dolomitize the limestone could be moved through the rock. This study, shows the the effect of dolomitization on limestone permeability is very important.

Rapid facies change can occur within a short lateral distance in the Floridan aquifer system, a result of closely spaced but highly variable depositional environments. Such changes may be textural within a limestone bed, such as an increase in the amount of micrite toward a relatively quiet water environment, or they may reflect, usually in an upbasin direction, the mixing of clastic materials with the limestone as one approaches an ancient shoreline. Complex interfingering and intertonguing of rock types and permeability conditions are thus produced, particularly in carbonate-clastic transition areas. The amount of fine-grained carbonate material in the Floridan aquifer system as a whole generally increases in a downbasin direction, so much so that, in parts of southern Florida, the aquifer system consists largely of low-permeability rocks separated by relatively thin, often vuggy, high-permeability zones that are hydraulically isolated from one another.

Geologic structure, like dolomitization, can either increase or decrease the permeability of a limestone. Because most limestones are relatively brittle, they tend to break rather than bend when they are subjected to stress. Joints are thus readily formed in carbonate rocks. In the Floridan aquifer system, borehole televiewer surveys and downhole current meter data show that, in places, joints cut some of the middle confining units and provide conduits along which water is able to move vertically from one permeable unit to another. Enlargement of joints can result from dissolution of limestone by ground water that moves along the joints. Data from wells in Brunswick, Ga. (well GA-GLY-9), and Broward County, Fla. (well FLA-BRO-2), show the effects of jointing on permeability. In contrast to the increase in permeability created by jointing, faults that cut all or part of the aquifer system may effectively decrease the permeability of the system in places and disrupt ground-water flow. The low-permeability materials downfaulted into the aquifer system in a series of grabens in western Alabama and central Georgia are examples of local decreases in permeability created by fault activity.

Most of the gypsum and anhydrite that fill the pore space in some of the confining units within the aquifer system apparently formed in a sabkha or other tidal flat environment. Petrographic examination of evaporite-rich limestone from a test well GA-WA-2 near Waycross, Ga.,however, shows that some of the evaporite minerals that fill the pore spaces in the limestone there were formed by secondary mineralization. Much of the anhydrite near Waycross appears to have been precipitated from ground water that was rich in calcium sulfate. Deposition of anhydrite or other types of pore-filling materials from circulating ground water has effectively decreased the porosity and permeability of the limestone near Waycross.

More commonly, circulating ground water increases the permeability of limestone by dissolution. Secondary porosity, developed as the carbonate rocks are partially dissolved, ranges in scale from pinpoint holes to isolated vugs to caverns tens of feet across. The larger solution conduits, of course, are the more important because they greatly increase the local transmissivity of the Floridan aquifer system. The karst features developed in the aquifer system are best known where the Floridan crops out or is thinly covered (pl. 25), but buried karst horizons, such as southern Florida's Boulder Zone, also occur and are of considerable importance. Stringfield (1966) discussed the near-surface karst features of the study area in detail.

It is obvious from the preceding discussion of th factors influencing the porosity and permeability o limestone that the distribution of permeability withir the Floridan aquifer system is extremely complex depending partly on the environment in which th limestone was deposited and partly on the postdeposi tional history of the rock. Certain generalizations ca be made, however, about the relation between th geologic character of the aquifer system and its hy draulic properties. Figure 27 shows the estimate distribution of transmissivity in the Upper Florida aquifer. Comparison of this figure with a map showin where the aquifer system is unconfined, thinly con fined, and thickly confined (pl. 25) shows that all area having transmissivity values greater than 1 × 10 ft^2/d, and many of the areas with values between 2.5 × 10^5 and 1.0 × 10^6 ft^2/d, occur where the aquifer syster is either unconfined or where its upper confining unit i less than 100 ft thick. In these places, the upper par of the aquifer system is riddled with caves, sinkhole pipes, and other types of solution features. The large scale secondary porosity developed in and near th Floridan's outcrop area is the reason for the larg

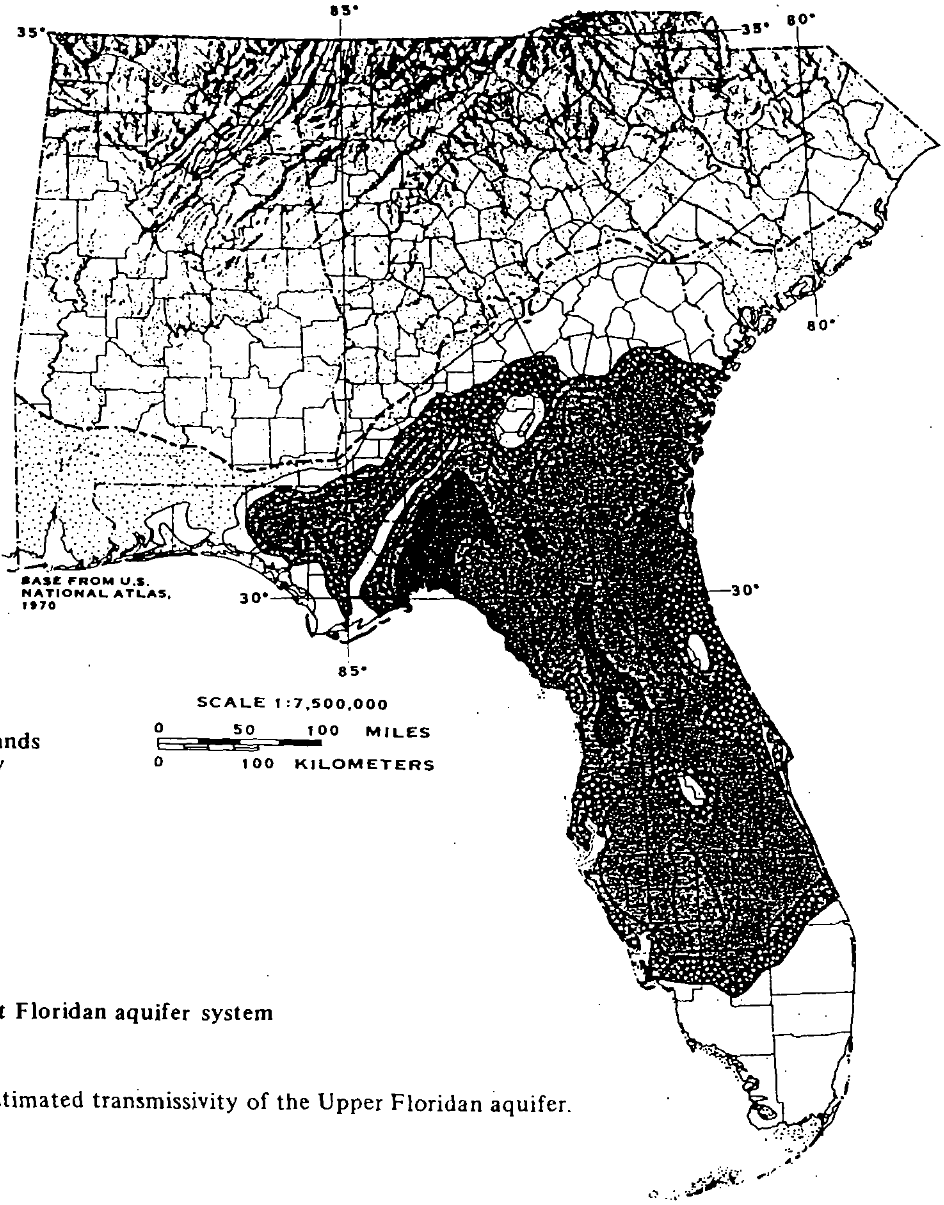


Figure 27. Estimated transmissivity of the Upper Floridan aquifer.

transmissivity values observed there. Where the aquifer system is thickly confined (pl. 25), its transmissivity is generally lower (less than 2.5×10^5 ft^2/d), and the variations that exist are related primarily to textural (facies) changes in the carbonate rocks and secondarily to the thickness of the Upper Floridan aquifer. For example, the mapped transmissivity values of less than 5×10^4ft^2/d in southern Florida result from a decrease in limestone permeability in an area where the aquifer system contains much micrite. Similar values near and just downdip of the aquifer system's updip limit (for example, in western panhandle Florida) are found in places where the Upper Floridan aquifer is thin (pl. 28). A band of low transmissivity extending northeastward across south-central Georgia is related to the small graben system called the Gulf Trough, discussed previously. Generally, then, the transmissivity of the aquifer system is most strongly influenced in and near its outcrop area by thickness and secondary permeability and, where the system is confined, by facies variations. A good example of this relation is shown by the upper Eocene rocks (Ocala Limestone) in figure 28. At Silver Springs, Fla., the Ocala is highly cavernous and forms the vents from which the springs issue (Faulkner, 1973). Downdip, these upper Eocene rocks become increasingly less permeable, chiefly because much of their pore space is filled either with micrite or finely recrystallized material, until, in Glades County, Fla. (well FLA-GL-1, fig. 28), upper Eocene rocks become part of the upper confining unit

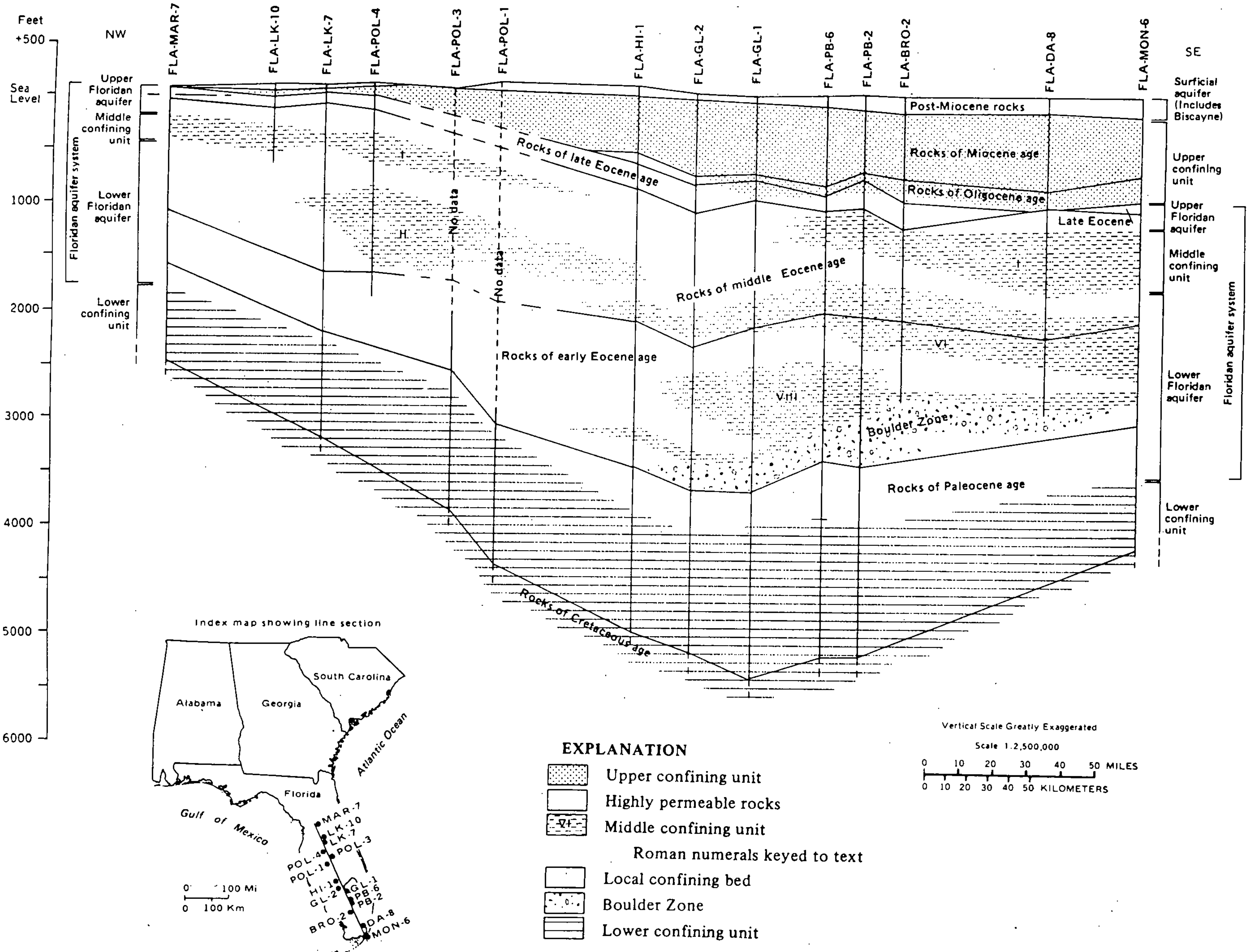


Figure 28. Generalized geohydrologic cross section from central Marion to northern Monroe Counties, Fla.

of the aquifer system. Farther south, as the amount of micrite in the Ocala decreases, upper Eocene rocks are again included as part of the aquifer system because their permeability is higher.

SUMMARY AND CONCLUSIONS

The Floridan aquifer system of the Southeastern United States is comprised of a thick sequence of carbonate rocks that are mostly of Paleocene to early Miocene age and that are hydraulically connected in varying degrees. Locally, the aquifer system includes rocks of Late Cretaceous age. In and near its outcrop area, the system consists of a single vertically continuous permeable unit. Downdip, there are generally two major permeable zones (the Upper and Lower Floridan aquifers) separated by a middle confining unit of subregional extent, whose hydraulic properties vary from very leaky to virtually nonleaky. Neither the vertical boundaries of the aquifer system nor its component major high- and low-permeability zones necessarily conform to either formation boundaries or time-stratigraphic breaks. Commonly, the permeability contrast that distinguishes the Floridan aquifer system from its upper and lower confining units occurs somewhere within a rock or time-rock unit.

The subsurface stratigraphy of the coastal plain rocks that comprise the Floridan aquifer system and its contiguous confining units was delineated and mapped on the basis of data from deep test wells of various types. Chronostratigraphic units were chosen for mapping because such units best portray conditions throughout an entire sedimentary basin when complex facies changes such as those found in the eastern Gulf Coast are present. Each chronostratigraphic unit that was delineated includes all or parts of several surface and subsurface formations. The external geometry of each chronostratigraphic unit is shown by structure contour and isopach maps, and internal variations in the units are shown on a series of cross sections that also portray major variations in permeability.

Coastal plain sediments in the eastern Gulf Coast are predominantly clastic from the Fall Line that marks their inland limit. These clastic rocks merge into and interfinger with a thick sequence of platform carbonate rocks that underlies all of peninsular Florida and much of southeastern Georgia. From Paleocene through Oligocene time, the platform carbonate facies successively encroached on the clastic rocks, the result being that progressively younger Tertiary carbonates extend progressively farther to the north and west. The general gentle seaward thickening of coastal plain rocks is interrupted by large- to small-scale geologic structures. Some of these structures, such as Florida's Peninsular arch, the Southeast and Southwest Georgia embayments, and the South Florida basin, have had a major influence on sedimentation and permeability distribution. The Gulf Trough fault system in central Georgia and the Gilbertown-Pickens-Pollard fault zone in southwestern Alabama both strongly influence ground-water flow within the Floridan aquifer system.

Rocks of Cretaceous age underlie the entire study area and generally consist of low-permeability calcareous clay and fine-textured limestone. Updip, sandy Cretaceous rocks form part of the lower confining unit of the Floridan aquifer system except very locally, in the Brunswick, Ga., area, where the upper Cretaceous Lawson Limestone is part of the system.

Paleocene rocks are generally of low permeability throughout the study area except for the permeable dolomite beds in the upper part of the Paleocene Cedar Keys Formation in peninsular Florida, which are included in the Floridan aquifer system. Thick extensive deposits of Paleocene anhydrite in the Florida peninsula form the base of the aquifer system there. Glauconitic Paleocene clastic rocks to the northwest are part of the aquifer system's lower confining unit. The Paleocene-early Eocene boundary is placed in this report at the highest occurrence of either of the planktic Foraminfera *Globorotalia pseudomenardii* Bolli or *G. Velascoensis* (Cushman).

Lower Eocene rocks in the Florida peninsula are part of the Oldsmar Formation, a sequence of limestone and dolomite beds that is in general highly permeable. Like the Paleocene rocks that underlie them, lower Eocene carbonate rocks grade to the north and west into calcareous, glauconitic clastic rocks that are of low permeability. Middle Eocene carbonate rocks in the Florida peninsula have traditionally been divided into the Lake City Limestone below and the Avon Park Limestone above. Well cuttings and core examined during this study show no consistent lithologic or paleontologic difference between the Lake City and Avon Park Limestones. Accordingly, this report proposes that the term Lake City be abandoned and that all middle Eocene carbonate strata in the Florida peninsula and contiguous areas be included in the Avon Park Formation. A reference well section is suggested for the expanded Avon Park Formation. This report further proposes that the term "formation" rather than "limestone" be applied to the Avon Park, Oldsmar, and Cedar Keys units because all commonly contain rock types other than limestone. Middle Eocene rocks show the same westward carbonate-to-clastic transition as lower Eocene and Paleocene strata. This transition occurs farther northward and westward than that of the lower Eocene, which is in turn north and west of the Paleocene clastic-carbonate transition. Most of the low-permea-

bility zones of subregional extent that occur within the Floridan aquifer system are part of the middle Eocene.

Upper Eocene strata consist mostly of carbonate rocks and represent the most widespread transgression of Tertiary seas in the Southeastern United States. Most upper Eocene beds in the study area are part of the highly permeable Ocala Limestone. The Oligocene strata that overlie the Ocala are also in general highly permeable and consist largely of carbonates. Oligocene rocks, however, are relatively thin throughout the study area and have been completely eroded from large areas in northeastern Florida and southeastern Georgia. In most places, either Oligocene or upper Eocene beds mark the top of the Floridan aquifer system.

Lower Miocene sandy limestones mark the end of carbonate bank depositional conditions in the study area. Beginning with the middle Miocene Hawthorn Formation, clastic rocks covered the eastern Gulf Coast almost everywhere. This clastic influx resulted in rapid and complex changes in rock type in the Hawthorn, and the widespread occurrence of Hawthorn phosphorites and high-silica clays show that the waters in the Hawthorn sea were colder than those in older Tertiary oceans. The marginal marine to fluvial origin of most post-Hawthorn rocks in the study area shows that there was a general regression of the sea after middle Miocene time. The upper confining unit of the Floridan aquifer system consists mostly of Hawthorn rocks but includes younger beds in places.

The term Floridan aquifer system is used in this report in place of the older terms "Floridan aquifer" or "principal artesian aquifer." The base of the Floridan aquifer system has been extended downward to include the upper part of the Cedar Keys Formation. The Hawthorn Formation, whose basal limestones have been included as part of the "Floridan aquifer" in older reports, is entirely excluded from the Floridan aquifer system in this report. The Floridan aquifer system generally consists of an Upper and a Lower Floridan aquifer separated by a low-permeability zone (middle confining unit) of subregional extent. In places, no middle confining unit is present, and the aquifer system is permeable throughout its vertical extent. In such places, the entire aquifer system is included in and mapped with its upper major permeable zone, the Upper Floridan aquifer.

Neither the top or base of the aquifer system nor the top or base of the aquifers and middle confining units within it conforms everywhere to the tops of stratigraphic units. Rather, the permeability contrasts that define the aquifer system and its component parts commonly occur within a formation or within a time-stratigraphic unit. Several stratigraphic units or parts of units may mark the top or base of the aquifer system regionally. Likewise, the subregional middle confining units of the aquifer system may consist of different stratigraphic units from place to place.

Hydraulic conditions within the Floridan aquifer system range from unconfined to confined, depending generally on the presence and integrity of low-permeability clastic rocks of Miocene age above the aquifer system. A sandy surficial aquifer is found throughout the study area and may be separated from the Floridan aquifer system by the system's upper confining unit or may be in direct contact with the system where the upper confining unit has been removed by erosion.

Maps of the top, base, and thickness of the Floridan aquifer system, maps of the top and thickness of the Upper and Lower Floridan aquifers, a series of geohydrologic cross sections, and a fence diagram portray the external and internal geometry of the aquifer system. Locally, there are zones of cavernous permeability developed within the aquifer system, and the larger of these cavernous zones are mapped.

The surficial aquifer that forms the uppermost hydrologic unit in the study area generally can be divided into three major parts: (1) the sand-and-gravel aquifer of southwestern Alabama and westernmost panhandle Florida, a thick sequence of fluvial gravelly sand beds; (2) the Biscayne aquifer of southeastern peninsular Florida, a sequence of sandy limestone and sand beds; and (3) a relatively thin but widespread blanket of fluvial to marine terrace sands that covers most of the study area. Water may leak downward from the surficial aquifer to the Floridan aquifer system or be discharged from the Floridan to the surficial aquifer, depending on the vertical hydraulic gradients at any given place.

The upper confining unit of the Floridan aquifer system is a generally thick sequence of clastic rocks and low-permeability carbonates that in places thins to a featheredge and in places is breached by sinkholes and other solution features. The upper confining unit creates the artesian conditions existing throughout most of the area where the Floridan aquifer system occurs. Where the upper confining unit, which consists mostly of rocks of the Hawthorn Formation, is thin or breached, semiconfined conditions exist in the Floridan aquifer system. The regional extent, character, and thickness of the upper confining unit have been mapped for the first time in this report.

Although the Floridan aquifer system is known to extend offshore, it has been mapped only to the coastline in this report. The top of the aquifer system may consist of different ages and types of rocks and its configuration as mapped is determined in part by large- to small-scale geologic features and in part by karst topography developed on the easily dissolved

limestone surface. The system's top in most places lies at the top of or within rocks of Oligocene age; where the Oligocene is absent, the system's top is at the top of or within rocks of late Eocene age. Locally, rocks of early Miocene or middle Eocene age comprise the system's top. Some of the small faults that cut the aquifer system's top in places locally limit the extent of the system, as in southwestern Alabama. Other faults, such as those in Florida, have no apparent effect on the system other than to offset its top by a slight amount. A series of small grabens in the central part of the Georgia coastal plain completely cuts the Floridan aquifer system, and movement along the faults that bound these grabens has juxtaposed low-permeability clastic rocks within the grabens opposite permeable limestone to either side and thereby created a damming effect on ground-water flow across the graben system.

The Floridan aquifer system generally thickens seaward from its outcrop area. This general trend is interrupted by several structural features of subregional scale. The Southeast Georgia embayment, the Southwest Georgia embayment, and the South Florida basin represent depocenters within which thick sequences of the carbonate rocks that comprise the Floridan aquifer system were deposited. The system thins over Florida's Peninsular arch. Although the Gulf Coast geosyncline was also a depocenter during Tertiary time, there was a large supply of clastic sediment to the geosyncline, in contrast to the carbonate bank type of depositional system that existed in peninsular Florida and contiguous areas. Accordingly, the Floridan aquifer system is thin around the northeastern rim of the Gulf Coast geosyncline because conditions were not favorable for carbonate deposition.

Within the Floridan aquifer system, there are subregional to local zones of high and low permeability. The uppermost zone of high permeability within the system, called the Upper Floridan aquifer in this report, nearly everywhere yields large volumes of water. The Upper Floridan generally consists of all or parts of rocks of Oligocene age and late Eocene age and the upper half of rocks of middle Eocene age. The thickness of the Upper Floridan as mapped depends partly on structural and depositional conditions and partly on the depth to one of the aquifer system's middle confining units, which form the base of the Upper Floridan.

Seven of the eight subregional low-permeability units that lie within the Floridan aquifer system act as middle confining units separating the Upper and Lower Floridan aquifers. The remaining confining unit lies within the Lower Floridan aquifer. The stratigraphic positions and the rock types of the different units vary greatly. In places, one of the middle confining units may overlie another. In this case, the higher of the overlapping zones is treated as the base of the Upper Floridan aquifer.

Subregional confining unit I, which extends as a coast-parallel band from the Florida Keys to southeastern South Carolina, consists of micritic limestone of middle Eocene age and is the leakiest middle confining unit identified. Subregional confining unit II, which is located in west-central peninsular Florida, consists of gypsiferous middle Eocene dolomite that forms a very low-permeability confining unit. Unit II is overlapped by unit I over a narrow band in central peninsular Florida. Middle confining unit III, located along the central part of the Georgia-Florida border, is gypsiferous, dolomitic middle Eocene limestone that, like unit II, is virtually nonleaky. Unit IV, in the eastern part of the Florida panhandle, is a glauconitic sandstone that extends tonguelike into the lower part of the Floridan aquifer system. Unit IV is of early middle Eocene age and appears to be a leaky confining unit. Middle confining unit V, located in the western Florida panhandle and in southern Alabama, is a massive, dark-colored, virtually nonleaky Oligocene clay. Unit VI, in southwestern peninsular Florida, is a series of low-permeability argillaceous limestone and coarsely crystalline dolomite beds. Unit VI is partly of middle Eocene age and partly of early Eocene age and is overlapped by parts of units I and II. Middle confining unit VII is a narrow strip of gypsiferous limestone of middle to late Eocene age that lies downgradient of and parallel to a small graben system in central Georgia. Restricted flow of ground water across the graben system has been insufficient to dissolve the gypsum from these rocks.

The Lower Floridan aquifer is that series of mostly permeable carbonate beds that lies beneath one of the middle confining units within the Floridan aquifer system. The Lower Floridan's flow system is sluggish, and its hydraulic characteristics are poorly known. In much of southern Florida, a cavernous zone of extremely high permeability occurs within the Lower Floridan aquifer. This interval, called the Boulder Zone, represents a paleokarst horizon that formed in early Eocene rocks. Other cavernous intervals occur in Florida from shallower depths, but they are not found over as wide an area as the Boulder Zone. The Boulder Zone is extensively used along Florida's southeastern coast as a storage zone for liquid wastes (chiefly treated municipal sewage). The Boulder Zone is overlain by a low-permeability micritic limestone that is mapped as middle confining unit VIII. In northeast Florida and southeast Georgia, another deep permeable zone, informally called the Fernandina permeable zone, occurs within the Lower Floridan aquifer in rocks of early Eocene age. The Fernandina permeable zone, which contains saline water, is separated from shallower

permeable zones in the Lower Floridan by a micritic limestone confining unit.

The lower confining unit of the Floridan aquifer consists in most places of either massive bedded anhydrite of Paleocene age (part of the Cedar Keys Formation) or glauconitic, calcareous clayey to sandy strata that range in age from late Paleocene to late Eocene. The base of the aquifer system is thus a composite surface that consists of different types and ages of rocks, all of which are of much lower permeability than the rocks of the overlying aquifer system. Some of the larger structural elements of the eastern gulf coast are recognizable on a map of the aquifer system's base. Variations in permeability within the Floridan aquifer system are complex. The porosity and permeability in the carbonate rocks that comprise the system result from a combination of (1) the original texture of the rock, as determined primarily by depositional environment; (2) the diagenetic processes that have acted on the sediment, such as dolomitization and recrystallization, and that are reflected by changes in mineralogy as well as porosity; (3) the joints, fractures, faults, and other structures that affect the integrity of the brittle carbonate rocks and open channels along which ground-water flow can be concentrated; (4) the dissolution of either the carbonate rocks themselves or pore-filling materials such as evaporites and a resulting increase in porosity; and (5) the precipitation of pore-filling minerals, specifically evaporites, either from seawater or from ground water. That most of the major features seen on a map of the potentiometric surface of the Floridan aquifer system can be explained by one of the above factors or a combination thereof demonstrates the effect of the geologic framework of the aquifer system on ground-water flow patterns within it.

REFERENCES

Applin, E. R., 1964, Some middle Eocene, lower Eocene, and Paleocene foraminiferal faunas from west Florida: Contributions from the Cushman Foundation for Foraminiferal Research, v. 15, pt. 2, p. 45-72.

Applin, E. R., and Applin, P. L., 1964, Logs of selected wells in the Coastal Plain of Georgia: Georgia Geological Survey Bulletin 74, 229 p.

Applin, E. R., and Jordan, Louise, 1945, Diagnostic foraminifera from subsurface formations in Florida: Journal of Paleontology, v. 19, no. 2, p. 129-148.

Applin, P. L., and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and southern Georgia: Bulletin of the American Association of Petroleum Geologists, v. 28, no. 12, p. 1673-1742.

———1967, The Gulf Series in the subsurface in northern Florida and southern Georgia: U.S. Geological Survey Professional Paper 524-G, 34 p.

Barnett, R. S., 1975, Basement structure of Florida and its tectonic implications: Gulf Coast Association of Geological Societies Transactions, v. 25, p. 122-142.

Barraclough, J. T., and Marsh, O. T., 1962, Aquifers and quality of ground water along the Gulf Coast of Florida: Florida Geological Survey Report of Investigations 29, 28 p.

Bennison, A. P., compiler, 1975, Geological highway map of the Southeastern Region: American Association of Petroleum Geologists, United States Geological Highway Map Series, Map 9, 1 sheet.

Berggren, W. A., 1965, Some problems of Paleocene-lower Eocene planktonic foraminiferal correlations: Micropaleontology, v. 11, p. 278-300.

———1971, Tertiary boundaries and correlations, *in* Funnell B. M., and Riedel, W. R., eds., Micropaleontology of the oceans: Cambridge University Press, p. 693-809.

———1977, Atlas of Palaeogene planktonic foraminifera, *in* Ramsey, A. T. S., ed., Oceanic micropaleontology: New York, Academic Press, v. 1, p. 205-299.

Blackwelder, B. W., and Ward, L. W., 1979, Stratigraphic revision of the Pliocene deposits of North and South Carolina: South Carolina Division of Geology, Geologic Notes, v. 23, no. 1, p. 33-49.

Boggess, D. H., 1974, Saline ground-water resources of Lee County, Florida: U.S. Geological Survey Open-File Report 74-247, 55 p.

Boggess, D. H., and O'Donnell, T. H., 1982, Deep artesian aquifers of Sanibel and Captiva Islands, Lee County, Florida: U.S. Geological Survey Open-File Report 82-253, 32 p.

Braunstein, Jules, ed., 1970, Bibliography of Gulf Coast geology: Gulf Coast Association of Geological Societies Special Publication 1, 1,045 p.

———1976, Bibliography of Gulf Coast geology: Gulf Coast Association of Geological Societies Special Publication 2, 318 p.

Brown, D. P., 1980, Geologic and hydrologic data from a test-monitor well at Fernandina Beach, Florida: U.S. Geological Survey Open-File Report 80-347, 36 p.

Brown, P. M., Miller, J. A., and Swain, F. M., 1972, Structural and stratigraphic framework and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geological Survey Professional Paper 796, 79 p.

Buono, Anthony, and Rutledge, A. T., 1979, Configuration of the top of the Floridan aquifer, Southwest Florida Water Management District and adjacent areas: U.S. Geological Survey Water-Resources Investigations 78-34, 1 sheet.

Bush, P. W., 1982, Predevelopment flow in the Tertiary limestone aquifer, Southeastern United States; a regional analysis from digital modeling: U.S. Geological Survey Water-Resources Investigations, 82-905, 41 p.

Bush, P. W., and Johnston, R. H., 1985, Summary of hydrology and ground-water development of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-C, [in press].

Bybell, L. M., 1980, Paleogene calcareous nannofossils; *in* Reinhardt, Juergen, and Gibson, T. G., eds., Upper Cretaceous and lower Tertiary geology of the Chattahoochee River Valley, western Georgia and eastern Alabama: Excursions in Southeastern geology, v. 2: Geological Society of America Annual Meeting, 93d, Atlanta 1980, Field Trip Guidebook, p. 416-421.

Callahan, J. T., 1964, The yield of sedimentary aquifers of the Coastal Plain southeast river basins: U.S. Geological Survey Water-Supply Paper 1669-W, 56 p.

Carr, W. J., and Alverson, D. C., 1959, Stratigraphy of middle Tertiary rocks of west-central Florida: U.S. Geological Survey Bulletin 1092, 109 p.

Cederstrom, D. J., Boswell, E. H., and Tarver, G. R., 1979, Summary appraisals of the Nation's ground-water resources—South

Atlantic-Gulf Region: U.S. Geological Survey Professional Paper 813-O, 35 p.

Chen, C. S., 1965, The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geological Survey Bulletin 45, 105 p.

Chowns, T. M., and Williams, C. T., 1983, Pre-Cretaceous rocks beneath the Georgia Coastal Plain—Regional implications; *in* Gohn, G. S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. L1-L42.

Cole, W. S., 1938, Stratigraphy and micropaleontology of two deep wells in Florida: Florida Geological Survey Bulletin 16, 73 p.

———1941, The stratigraphic and paleontologic studies of wells in Florida: Florida Geological Survey Bulletin 19, 91 p.

———1942, Stratigraphic and paleontologic studies of wells in Florida—No. 2: Florida Geological Survey Bulletin 20, 89 p.

———1944, Stratigraphic and paleontologic studies of wells in Florida—No. 3: Florida Geological Survey Bulletin 26, 168 p.

———1945, Stratigraphic and paleontologic studies of wells in Florida—No. 4: Florida Geological Survey Bulletin 28, 160 p.

Cole, W. S., and Gravell, D. W., 1952, Middle Eocene foraminifera from Penon seep, Matanzoas Province, Cuba: Journal of Paleontology, v. 26, no. 5, p. 708-727.

Cooke, C. W., 1915, The age of the Ocala limestone: U.S. Geological Survey Professional Paper 95-I, p. 107-117.

———1943, Geology of the Coastal Plain of Georgia: U.S. Geological Survey Bulletin 941, 121 p.

———1945, Geology of Florida: Florida Geological Survey Bulletin 29, 339 p.

Cooke, C. W., and Mansfield, W. C., 1936, Suwannee limestone of Florida [abs.]: Geological Society of America Proceedings, 1935, p. 71-72.

Cooke, C. W., and Mossum, Stuart, 1929, Geology of Florida, *in* Florida Geological Survey 20th Annual Report: Tallahassee, p. 29-229.

Copeland, C. W., 1968, Geology of the Alabama Coastal Plain: Alabama Geological Survey Circular 47, 97 p.

Counts, H. B., and Donsky, Ellis, 1963, Salt-water encroachment, geology and ground-water resources of Savannah area, Georgia and South Carolina: U.S. Geological Survey Water-Supply Paper 1611, 100 p.

Cushman, J. A., 1935, Upper Eocene foraminifera of the Southeastern United States: U.S. Geological Survey Professional Paper 181, 88 p.

———1951, Paleocene foraminifera of the Gulf coastal region of the United States and adjacent areas: U.S. Geological Survey Professional Paper 232, 75 p.

Cushman, J. A., and Ponton, G. M., 1932, The foraminifera of the upper, middle, and part of the lower Miocene of Florida: Florida Geological Survey Bulletin 9, 197 p.

Dall, W. H., and Harris, G. D., 1892, Correlation papers—Neocene: U.S. Geological Survey Bulletin 84, 349 p.

DuBar, J. R., 1958, Stratigraphy and paleontology of the late Neogene strata of the Caloosahatchee River area of southern Florida: Florida Geological Survey Bulletin 40, 267 p.

Faye, R. E., and Prowell, D. C., 1982, Effects of Late Cretaceous and early Tertiary faulting on the geology and hydrology of the Coastal Plain near the Savannah River, Georgia and South Carolina: U.S. Geological Survey Open-File Report 82-156, 73 p.

Faulkner, G. L., 1973, Geohydrology of the Cross-Florida Barge Canal area, with special reference to the Ocala vicinity: U.S. Geological Survey Water-Resources Investigations 1-73, 117 p.

Folk, R. L., 1959, Practical classification of limestones: Bulletin of the American Association of Petroleum Geologists, v. 43, no. 1, p. 1-38.

Franks, B. F., ed., 1982, Principal aquifers in Florida: U.S. Geological Survey Water-Resources Investigations 82-255, 4 sheets.

Frederiksen, N. O., Gibson, T. G., and Bybell, L. M., 1982, Paleocene-Eocene boundary in the eastern Gulf Coast: Gulf Coast Association of Geological Societies Transactions, v. 32, p. 289-294.

Gelbaum, Carol, 1978, The geology and ground water of the Gulf Trough: Georgia Geologic Survey Bulletin 93, p. 38-47.

Gelbaum, Carol, and Howell, Julian, 1982, The geohydrology of the Gulf Trough, *in* Arden, P. D., Beck, B. F., and Morrow, Elanore, eds., Proceedings of the Second Symposium on the Geology of the Southeastern Coastal Plain: Georgia Geologic Survey Information Circular 53, p. 140-153.

Geological Society of America, 1951, Rock color chart: Boulder.

Georgia Geological Survey, 1976, Geologic map of Georgia: Atlanta, scale 1:500,000.

Gibson, T. G., 1980, Facies changes of lower Paleocene strata, *in* Reinhardt, Juergen, and Gibson, T. G., eds., Upper Cretaceous and lower Tertiary geology of the Chattahoochee River valley, western Georgia and eastern Alabama: Excursions in Southeastern geology, v. 2: Geological Society of America, Annual Meeting, 93d, Atlanta 1980, Field Trip Guidebook, p. 402-411.

———1982a, New stratigraphic unit in the Wilcox Group (upper Paleocene-lower Eocene) in Alabama and Georgia: U.S. Geological Survey Bulletin 1529-H, p. H23-H32.

———1982b, Revision of the Hatchetigbee and Bashi Formations (lower Eocene) in the eastern Gulf Coastal Plain: U.S. Geological Survey Bulletin 1529-H, p. H33-H41.

Gibson, T. G., Mancini, E. A., and Bybell, L. M., 1982, Paleocene to middle Eocene stratigraphy of Alabama: Gulf Coast Association of Geological Societies Transactions, v. 32, p. 449-458.

Gohn, G. S., Hazel, J. E., Bybell, L. M., and Edwards, L. E., 1983, The Fishburne Formation (lower Eocene), a newly defined subsurface unit in the South Carolina Coastal Plain: U.S. Geological Survey Bulletin 1537-C, 16 p.

Gohn, G. S., Higgins, B. B., Smith, C. C., and Owens, J. P., 1977, Lithostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina: U.S. Geological Survey Professional Paper 1028-E, p. E59-E70.

Guyton and Associates, 1976, Hydraulics and water quality: Engineering report prepared for Swift Agricultural Chemicals Corporation, Manatee Mine site: Houston, 78 p.

Hanshaw, B. B., and Back, William, 1979, Major geochemical processes in the evolution of carbonate-aquifer systems: Journal of Hydrology, v. 43, p. 287-312.

Hanshaw, B. B., Back, William, and Deike, R. G., 1971, A geochemical hypothesis for dolomitization by ground water: Economic Geology, v. 66, no. 5, p. 710-724.

Hayes, L. R., 1979, The ground-water resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina: South Carolina Water Resources Commission Report 9, 91 p.

Hayes, L. R., Maslia, M. L., and Meeks, W. C., 1983, Hydrology and model evaluation of the principal artesian aquifer, Dougherty Plain, southwest Georgia: Georgia Geologic Survey Bulletin 97, 91 p.

Hazel, J. E., Bybell, L. M., Christopher, R. A., Frederickson, N. O., May, F. E., McLean, D. M., Poore, R. Z., Smith, C. C., Sohl, N. F., Valentine, P. C., and Witmer, R. J., 1977, Biostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina: U.S. Geological Survey Professional Paper 1028-F, p. F71-F89.

Hazel, J. E., Mumma, M. D., and Huff, W. J., 1980, Ostracode biostratigraphy of the lower Oligocene (Vicksburgian) of Mississippi and Alabama: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 361-401.

Healy, H. G., 1975, Terraces and shorelines of Florida: Florida Division of Geology Map Series 71, scale 1:2,000,000.

Heath, R. C., and Conover, C. S., 1981, Hydrologic almanac of Florida: U.S. Geological Survey Open-File Report 81-1107, 239 p.

Hendry, C. W., Jr., and Sproul, C. R., 1966, Geology and ground-water resources of Leon County, Florida: Florida Geological Survey Bulletin 47, 178 p.

Herrick, S. M., 1961, Well logs of the Coastal Plain of Georgia: Georgia Geological Survey Bulletin 70, 462 p.

Herrick, S. M., and Vorhis, R. C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Geological Survey Information Circular 25, 79 p.

Huddlestun, P. F., 1981, Correlation chart, Georgia Coastal Plain: Georgia Geologic Survey Open-File Report 82-1, 1 sheet.

Huddlestun, P. F., and Hetrick, J. H., 1978, Stratigraphy of the Tobacco Road Sand—A new formation; *in* Short contributions to the geology of Georgia: Georgia Geologic Survey Bulletin 93, p. 56-77.

Hyde, L. W., 1975, Principal aquifers in Florida: Florida Division of Geology Map Series 16 (revised), scale 1:2,000,000, 1 sheet.

Johnston, R. H., and Bush, P. W., 1985, Summary of the Hydrology of the Floridan Aquifer System in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-C, [in press].

Johnston, R. H., Bush, P. W., Krause, R. E., Miller, J. A., and Sprinkle, C. L., 1982, Summary of hydrologic testing in Tertiary limestone aquifer, Tenneco offshore exploratory well—Atlantic OCS, lease-block 427 (Jacksonville NH 17-5): U.S. Geological Survey Water-Supply Paper 2180, 15 p.

Johnston, R. H., Krause, R. E., Meyer, F. W., Ryder, P. D., Tibbals, C. H., and Hunn, J. D., 1980, Estimated potentiometric surface for the Tertiary limestone aquifer system, Southeastern United States, prior to development: U.S. Geological Survey Open-File Report 80-406, 1 sheet.

Johnston, R. H., Healy, M. G., and Hayes, L. R., 1981, Potentiometric surface of the Tertiary limestone aquifer system, southeastern United States, May 1980: U.S. Geological Survey Open-File Report 81-486, 1 sheet.

King, K. C., and Wright, Ramil, 1979, Revision of the Tampa Formation, west-central Florida: Gulf Coast Association of Geological Societies Transactions, v. 29, p. 257-262.

Klein, Howard, 1972, The shallow aquifer of southwest Florida: Florida Division of Geology Map Series 53, 1 sheet.

Klein, Howard, and Hull, J. E., 1978, Biscayne aquifer, southeast Florida: U.S. Geological Survey Water-Resources Investigations 78-107, 52 p.

Knapp, M. S., 1979, Top of the Floridan aquifer of north-central Florida: Florida Division of Geology Map Series 92, 1 sheet.

Kohout, F. A., 1965, A hypothesis concerning cyclic flow of salt-water related to geothermal heating in the Floridan aquifer: Transactions of the New York Academy of Sciences, ser. II, v. 28, no. 2, p. 249-271.

Krause, R. E., 1979, Geohydrology of Brooks, Lowndes, and western Echols Counties, Georgia: U.S. Geological Survey Water-Resources Investigations 78-117, 48 p.

———1982, Digital model evaluation of the predevelopment flow system of the Tertiary limestone aquifer system, southeast Georgia, northeast Florida, and southern South Carolina: U.S. Geological Survey Water-Resources Investigations 82-173, 27 p.

Krause, R. E., and Randolph, R. B., 1985, Hydrology of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina: U.S. Geological Survey Professional Paper 1403-D, [in press].

Kwader, Thomas, and Schmidt, Walter, 1978, Top of the Floridan aquifer of northwest Florida: Florida Division of Geology Map Series 86, scale 1:500,000, 1 sheet.

LaMoreaux, P. E., 1946, Geology and ground-water resources of the Coastal Plain of east-central Georgia: Georgia Geological Survey Bulletin 52, 173 p.

Leighton, M. W., and Pendexter, C., 1962, Carbonate rock types, *in* Ham, W. E., ed., Classification of carbonate rocks: American Association of Petroleum Geologists Memoir 1, p. 33-61.

Leve, G. W., 1970, Report on geophysical and television explorations in city of Jacksonville water wells: Florida Division of Geology Information Circular 64, 15 p.

Leve, G. W., and Goolsby, D. A., 1967, Test hole in aquifer with many water-bearing zones at Jacksonville, Florida: Ground Water, v. 5, no. 4, p. 18-22.

Levin, H. L., 1957, Micropaleontology of the Oldsmar Limestone (Eocene) of Florida: Micropaleontology, v. 3, no. 2, p. 137-154.

Lichtler, W. F., Anderson, Warren, and Joyner, B. F., 1968, Water resources of Orange County, Florida: Florida Division of Geology Report of Investigations 50, 150 p.

Loeblich, A. R., Jr., and Tappan, Helen, 1957, Planktonic foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic Coastal Plains: United States National Museum Bulletin 215, p. 173-198.

MacNeil, F. S., 1944, Oligocene stratigraphy of Southeastern United States: Bulletin of the the American Association of Petroleum Geologists, v. 28, p. 1313-1354.

———1950, Pleistocene shorelines of Florida and Georgia: U.S. Geological Survey Professional Paper 221-F, p. F95-F107.

Maher, J. C., 1965, Correlations of subsurface Mesozoic and Cenozoic rocks along the Atlantic coast: Tulsa, Okla., American Association of Petroleum Geologists, 18 p.

———1971, Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf: U.S. Geological Survey Professional Paper 659, 98 p.

Maher, J. C., and Applin, E. R., 1968, Correlation of subsurface Mesozoic and Cenozoic rocks along the eastern Gulf Coast: American Association of Petroleum Geologists Cross Section Publication 6, 29 p.

Marsh, O. T., 1966, Geology of Escambia and Santa Rosa Counties, western Florida panhandle: Florida Geological Survey Bulletin 46, 140 p.

McCollum, M. J., and Herrick, S. M., 1964, Offshore extension of the upper Eocene to recent stratigraphic sequence in southeastern Georgia: U.S. Geological Survey Professional Paper 501-C, p. C61-C63.

Meyer, F. W., 1962, Reconnaissance of the geology and ground-water resources of Columbia County, Florida: Florida Division of Geology Report of Investigations No. 30, 74 p.

———1974, Evaluation of hydraulic characteristics of a deep artesian aquifer from natural water-level fluctuations, Miami, Florida: Florida Division of Geology Report of Investigations 75, 32 p.

Miller, J. A., 1978, Geologic and geophysical data from Osceola National Forest, Florida: U.S. Geological Survey Open-File Report 78-799, 101 p.

———1979, Potential subsurface zones for liquid-waste storage in Florida: Florida Division of Geology Map Series 94, scale 1:2,000,000.

———1982a, Geology and configuration of the top of the Tertiary limestone aquifer system, Southeastern United States: U.S. Geological Survey Water-Resources Investigations 81-1178, scale 1:1,000,000.

———1982b, Configuration of the base of the upper permeable zone of the Tertiary limestone aquifer system, Southeastern United States: U.S. Geological Survey Water-Resources Investigations, 81-1177, scale 1:1,000,000.

———1982c, Geology and configuration of the base of the Tertiary

limestone aquifer system, Southeastern United States: U.S. Geological Survey Water-Resources Investigations 81-1176, scale 1:1,000,000, 1 sheet.

———1982d, Thickness of the upper permeable zone of the Tertiary limestone aquifer system, Southeastern United States: U.S. Geological Survey Water-Resources Investigations 81-1179, scale 1:1,000,000, 1 sheet.

———1982e, Thickness of the Tertiary limestone aquifer system, Southeastern United States: U.S. Geological Survey Water Resources Investigations 81-1124, scale 1:1,000,000, 1 sheet.

———1982f, Structural and sedimentary setting of phosphorite deposits in North Carolina and in northern Florida; *in* Scott, T. B., and Upchurch, S. B., eds., Miocene of the Southeastern United States: Florida Geological Survey Special Publication 25, p. 162-182.

———1982g, Structural control of Jurassic sedimentation in Alabama and Florida: Bulletin of the American Association of Petroleum Geologists, v. 66, no. 9, p. 1289-1301.

———1984, Data from selected wells in the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Open-File Report [in press].

Miller, J. A., Hughes, G. H., Hull, R. W., Vecchioli, John, and Seaber, P. R., 1978, Impact of potential phosphate mining on the hydrology of Osceola National Forest, Florida: U.S. Geological Survey Water-Resources Investigations 78-6, 159 p.

Moore, D. B., 1971, Subsurface geology of southwest Alabama: Alabama Geological Survey Bulletin 99, 80 p.

Moore, W. E., 1955, Geology of Jackson County, Florida: Florida Geological Survey Bulletin 37, 101 p.

Murray, G. E., 1947, Cenozoic deposits of central Gulf Coastal Plain: Bulletin of the American Association of Petroleum Geologists, v. 31, no. 10, p. 1825-1850.

———1955, Midway stage, Sabine stage, and Wilcox group: Bulletin of the American Association of Petroleum Geologists, v. 39, p. 671-696.

———1961, Geology of the Atlantic and Gulf Coastal Province of North America: New York, Harper, 692 p.

Musgrove, R. H., Barraclough, J. T., and Marsh, O. T., 1961, Interim report on the water resources of Escambia and Santa Rosa Counties, Florida: Florida Division of Geology Information Circular No. 30, 89 p.

Neathery, T. L., and Thomas, W. A., 1975, Pre-Mesozoic basement rocks of the Alabama Coastal Plain: Gulf Coast Association of Geological Societies Transactions, v. 25, p. 86-99.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: Bulletin of the American Association of Petroleum Geologists, v. 67, no. 5, p. 841-875.

Oliver, G. E., and Mancini, E. A., 1980, Late Paleocene planktic foraminiferal biostratigraphy of the Tuscahoma marls in southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 467-472.

Parker, G. G., and Cooke, C. W., 1944, Late Cenozoic geology of southern Florida, with a discussion of the ground water: Florida Geological Survey Bulletin 27, 119 p.

Parker, G. G., Ferguson, G. E., Love, S. K., and others, 1955, Water resources of southeastern Florida: U.S. Geological Survey Water-Supply Paper 1255, 965 p.

Patterson, S. H., and Herrick, S. M., 1971, Chattahoochee anticline, Apalachicola embayment, Gulf trough and related structural features, southwestern Georgia, fact or fiction: Georgia Geological Survey Information Circular 41, 16 p.

Poag, Wiley, 1972, Planktonic foraminifera of the Chickasawhay Formation, U.S. Gulf Coast: Micropaleontology, v. 18, p. 257-277.

Pooser, W. K., 1965, Biostratigraphy of Cenozoic Ostracoda from South Carolina: University of Kansas Paleontological Contributions, article 8, 80 p.

Postuma, J. A., 1971, Manual of planktonic foraminifera: New York, Elsevier, 420 p.

Puri, H. S., 1953a, Contribution to the study of the Miocene of the Florida Panhandle: Florida Geological Survey Bulletin 36, 345 p.

———1953b, Zonation of the Ocala group in peninsular Florida: Journal of Sedimentary Petrology, v. 23, p. 130.

———1957, Stratigraphy and zonation of the Ocala Group: Florida Geological Survey Bulletin 38, 248 p.

Puri, H. S., and Vernon, R. O., 1964, Summary of the geology of Florida and a guide book to the classic exposures: Florida Geological Survey Special Publication 5, revised ed., 255 p.

Randazzo, A. F., and Hickey, E. W., 1978, Dolomitization in the Floridan aquifer: American Journal of Science, v. 278, p. 1177-1184.

Randazzo, A. F., Stone, G. C., and Saroop, H. C., 1977, Diagenesis of middle and upper Eocene carbonate shoreline sequences, central Florida: Bulletin of the American Association of Petroleum Geologists, v. 61, no. 4, p. 492-503.

Reinhardt, Juergen, and Gibson, T. G., eds., 1980, Upper Cretaceous and lower Tertiary geology of the Chattahoochee River valley, western Georgia and eastern Alabama: Excursions in Southeastern geology, v. 2: Geological Society of America Annual Meeting, 93d Atlanta 1980, Field Trip Guidebook, p. 385-463.

Renfro, H. B., 1970, Geological highway map of the mid-Atlantic region: American Association of Petroleum Geologists, U.S. Geological Highway Map Series, Map 4, 1 sheet.

Riggs, S. R., 1979, Phosphorite sedimentation in Florida—A model phosphogenic system: Economic Geology, v. 74, no. 2, p. 285-315.

Rosenau, J. C., Faulkner, G. L., Hendry, C. W., Jr., and Hull, R. W., 1977, Springs of Florida: Florida Division of Geology Geologic Bulletin 31, revised, 461 p.

Ryder, P. D., 1982, Digital model of predevelopment flow in the Tertiary limestone (Floridan) aquifer system in west-central Florida: U.S. Geological Survey Water-Resources Investigations 81-54, 82 p.

———1985, Hydrology of the Floridan aquifer system in west-central Florida: U.S. Geological Survey Professional Paper 1403-F [in press].

Sanders, A. E., Weems, R. E., and Lenson, E. M., Jr., 1982, Chandler Bridge Formation—A new Oligocene stratigraphic unit in the lower Coastal Plain of South Carolina: U.S. Geological Survey Bulletin 1529-H, p. H105-H124.

Schlee, John, 1977, Stratigraphy and Tertiary development of the continental margin east of Florida: U.S. Geological Survey Professional Paper 581-F, 25 p.

Schroeder, M. C., Klein, Howard, and Hoy, N. D., 1958, Biscayne aquifer of Dade and Broward Counties, Florida: Florida Division of Geology Report of Investigations 17, 56 p.

Scott, T. M., and Hajishafie, M., 1980, Top of Floridan aquifer in the St. Johns Water Management District: Florida Division of Geology Map Series 95, scale 1:500,000, 1 sheet.

Scott, T. M., and Upchurch, S. B., eds., 1982, Miocene of the Southeastern United States: Florida Division of Geology Special Publication 25, 319 p.

Simpson, G. G., 1932, A new Paleocene mammal from a deep well in Louisiana: United States National Museum Proceedings, v. 82, article 2, 4 p.

Siple, G. E., 1967, Geology and ground water of the Savannah River Plant and vicinity, South Carolina: U.S. Geological Survey Water-Supply Paper 1841, 113 p.

Snell, L. J., and Anderson, Warren, 1970, Water resources of north-

east Florida: Florida Division of Geology Report of Investigations 54, 77 p.

Sprinkle, C. L., 1985, Geochemistry of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-I [in press].

Stainforth, R. M., Lamb, J. L., Luterbacher, Manspeter, Beard, J. H., and Jeffords, R. M., 1975, Cenozoic planktonic foraminiferal zonation and characteristics of index forms: University of Kansas Paleontological Contributions, article 62, 425 p.

Stephenson, L. W., and Veatch, J. O., 1915, Underground waters of the Coastal Plain of Georgia: U.S. Geological Survey Water-Supply Paper 341, 539 p.

Stringfield, V. T., 1936, Artesian water in the Floridan peninsula: U.S. Geological Survey Water-Supply Paper 773-C, p. C115-C195.

———1966, Artesian water in Tertiary limestone in the Southeastern States: U.S. Geological Survey Professional Paper 517, 226 p.

Sutcliffe, Horace, Jr., 1975, Appraisal of the water resources of Charlotte County, Florida: Florida Division of Geology Report of Investigations 78, 53 p.

Tibbals, C. H., 1985, Hydrology of the Floridan aquifer system in east-central Florida: U.S. Geological Survey Professional Paper 1403-E [in press].

Toulmin, L. D., 1940, The Salt Mountain Limestone of Alabama: Alabama Geological Survey Bulletin 46, 126 p.

———1977, Stratigraphic distribution of Paleocene and Eocene fossils in the eastern Gulf Coast region: Alabama Geological Survey Monograph 13, v. 1, 602 p.

Trapp, Henry, Jr., 1978, Preliminary hydrologic budget of the sand-and-gravel aquifer under unstressed conditons, *with a section on* Water-quality monitoring, Pensacola, Florida: U.S. Geological Survey Water-Resources Investigations 77-96, 57 p.

Vail, P. R., Mitchum, R. M., Jr., and Thompson, S., III, 1977, Global cycles of relative changes of sea level, *in* Payton, C. E., ed., Seismic stratigraphy—Applications to hydrocarbon exploration: Memoir of the American Association of Petroleum Geologists 26, p. 83-97.

Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geological Survey Bulletin 33, 256 p.

———1970, The beneficial uses of zones of high transmissivity in the Floridan subsurface for water storage and waste disposal: Florida Division of Geology Information Circular 70, 39 p.

———1973, Top of the Floridan aquifer: Florida Division of Geology Map Series 56, scale 1:2,000,000, 1 sheet.

Vernon, R. O., and Puri, H. S., 1965, Geologic map of Florida: Florida Division of Geology Map Series 18, scale 1:2,000,000, 1 sheet.

Ward, L. W., Blackwelder, B. W., Gohn, G. S., and Poore, R. Z., 1979, Stratigraphic revision of Eocene, Oligocene, and lower Miocene Formations of South Carolina: South Carolina Division of Geology Geologic Notes, v. 23, no. 1, p. 2-32.

Warren, M. A., 1944, Artesian water in southeastern Georgia, with special reference to the coastal area: Georgia Geological Survey Bulletin 49, 140 p.

Weaver, C. E., and Beck, K. C., 1977, Miocene of the southeastern United States; a model for chemical sedimentation in a perimarine environment: New York, Elsevier, 234 p.

Weems, R. E., Lemon, E. M., Jr., McCartan, Lucy, Bybell, L. M., and Sanders, A. E., 1982, Recognition and formalization of the Pliocene "Goose Creek phase" in the Charleston, South Carolina, area: U.S. Geological Survey Bulletin 1529-H, p. H137-H148.

Wind, F. H., 1974, Calcareous nannoplankton of the Salt Mountain Limestone (Jackson, Alabama): Gulf Coast Association of Geological Societies Transactions, v. 24, p. 327-329.

Winston, G. O., 1971, The Dollar Bay Formation of Lower Cretaceous (Fredericksburg) age in south Florida—Its stratigraphy and petroleum possibilities: Florida Division of Geology Special Publication 15, 99 p.

———1976, Florida's Ocala Uplift is not an uplift: Bulletin of the American Association of Petroleum Geologists, v. 60, no. 6, p. 992-994.

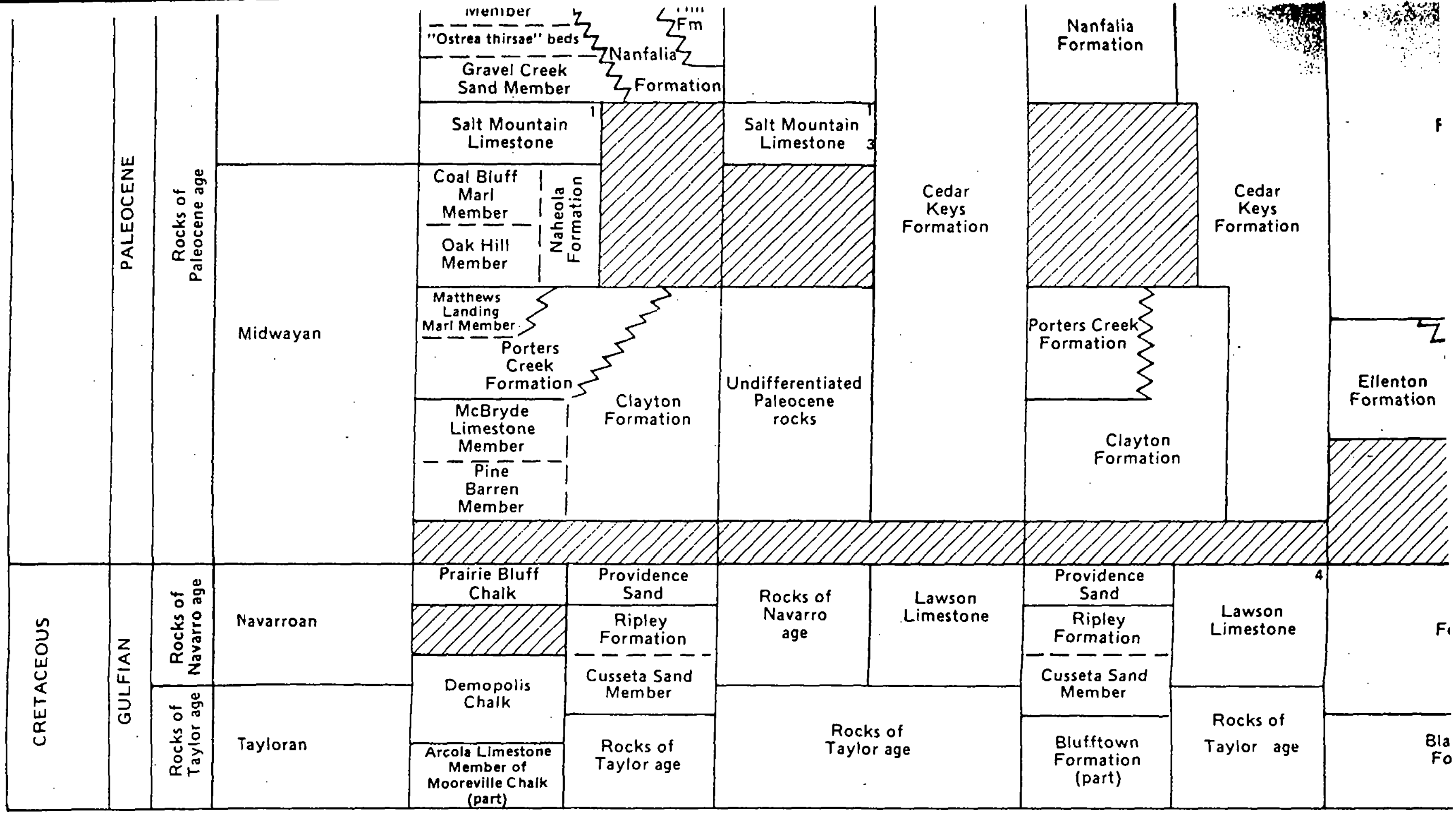
Wolansky, R. M., Barr, G. L., and Spechler, R. M., 1979, Generalized configuration of the bottom of the Floridan aquifer, Southwest Floridan Water Management District: U.S. Geological Survey Open-File Report 79-1490, 1 sheet.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROFESSION

SYSTEM	SERIES	UNIT MAPPED IN THIS REPORT	GULF COAST STAGE	ALABAMA West	ALABAMA East	FLORIDA Panhandle	FLORIDA Peninsula	GEORGIA	SOU
QUATERNARY	HOLOCENE	Post-Miocene rocks	Post - Glacial	Undifferentiated Deposits		Undifferentiated Deposits		Undifferentiated Deposits	Un
QUATERNARY	PLEISTOCENE	Post-Miocene rocks	Wisconsin to Nebraskan	Terrace deposits		Terrace deposits	Undifferentiated terrace and shallow marine deposits	Terrace deposits	
	PLEISTOCENE	Post-Miocene rocks					Caloosahatchee Formation and equivalents		W F
	PLIOCENE	Post-Miocene rocks	Foleyan	Citronelle Formation		Citronelle Formation	Bone Valley Formation; Tamiami Formation	Charlton Formation; Raysor Formation	Raysor Formation
	MIOCENE	Rocks of Miocene age	Clovellian Ducklakian Napoleonvillian	Undifferentiated deposits		Alum Bluff Group	Undifferentiated upper Miocene deposits		
	MIOCENE	Rocks of Miocene age				Alum Bluff Group	Hawthorn Formation	Hawthorn Formation	Hawthc
	MIOCENE	Rocks of Miocene age	Anahuacian	Catahoula Sandstone (restricted)		Tampa Limestone [2]			Edisto Formation
	OLIGOCENE	Rocks of Oligocene age	Chickasawhayan (restricted)	Paynes Hammock Formation				Cooper Formation (part)	Char F
	OLIGOCENE	Rocks of Oligocene age	Chickasawhayan (restricted)	Chickasawhay Formation (restricted)		Chickasawhay Formation	Suwannee Limestone	Suwannee Limestone; Cooper Formation (part)	Ashley Member
	OLIGOCENE	Rocks of Oligocene age	Vicksburgian	Vicksburg Group: Buckatunna Formation		Buckatunna Formation	Suwannee Limestone		
	OLIGOCENE	Rocks of Oligocene age	Vicksburgian	Vicksburg Group: Byram Formation			Suwannee Limestone		
	OLIGOCENE	Rocks of Oligocene age	Vicksburgian	Vicksburg Group: Glendon Formation					
	OLIGOCENE	Rocks of Oligocene age	Vicksburgian	Vicksburg Group: Mint	Marianna	Marianna			

TERTIARY	EOCENE		Vicksburgian	Vicks[burg]: Glendon Formation; Mint Spring Formation / Marianna Formation; Forest Hill Formation / Red Bluff Formation / Bumpnose Formation	Marianna Formation Bumpnose Formation				
		Rocks of late Eocene age	Jacksonian	Yazoo Clay: Shubuta Member; Puchuta Marl Member; Cocoa Sand Member; North Twistwood Creek Clay Member Ocala Limestone Moodys Branch Formation	Ocala Limestone Moodys Branch Formation 3		Ocala Limestone	Cooper Fm (part) Tobacco Road Sand Barnwell Formation: Irwinton Sand Member; Twiggs Clay Member Clinchfield Sand	Parkers Fer[ry] Member Harleyvill[e] Member
		Rocks of middle Eocene age	Claibornian	Gosport Formation Lisbon Formation Tallahatta Formation	Lisbon Formation 3 Tallahatta Formation	Avon Park Formation Lake City Limestone †	Lisbon Formation Tallahatta Formation Avon Park Formation Lake City Limestone †	McBean Formation Santee Limestone Huber (?) Formation	Santee Limestone: Cross Membe[r]; Moultri[e] Membe[r]
		Rocks of early Eocene age	Sabinian	Hatchetigbee Formation Bashi Formation	Undifferentiated lower Eocene rocks	Oldsmar Formation	Hatchetigbee Formation	Oldsmar Formation	Fishburn[e]
	[PALEOCE]NE			Bells Landing Marl Member Greggs Landing Marl Member Tuscahoma Formation	Undifferentiated Paleocene rocks		Tuscahoma Formation		
				Grampian Hills Member "Ostrea thirsae" beds Gravel Creek Sand Member Nanfalia Formation Baker Hill Fm			Nanfalia Formation		E[...] M[...] For[...]
				Salt Mountain Limestone 1	Salt Mountain Limestone 3				



FOOTNOTES:

1 Local, mostly subsurface

2 Includes St. Marks Formation in west Florida

3 Geographically extended on basis of this study

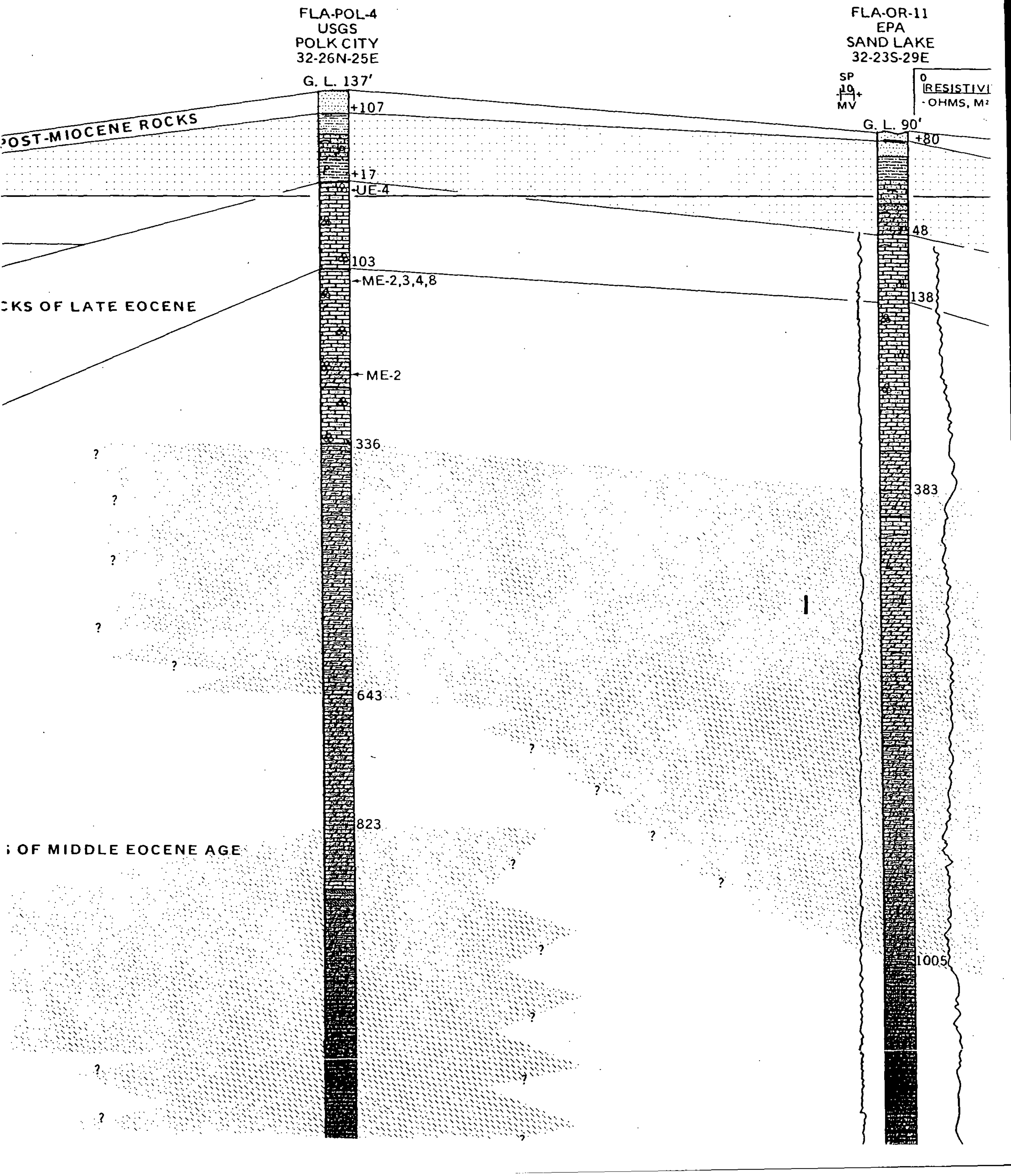
4 Unit is very locally part of the Floridan aquifer system

† Abandoned

Units in blue are part of the Floridan aquifer system

Generalized correlation chart for stratigraphic units showing the position of Floridan aquifer syst

INTERIOI



FLA-POL-4
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POLK CITY
32-26N-25E
G. L. 137′
+107
+17
UE-4
103
ME-2,3,4,8
ME-2
336
643
823
FLA-OR-11
EPA
SAND LAKE
32-23S-29E
SP
10
MV
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RESISTIVI
OHMS, M²
G. L. 90′
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48
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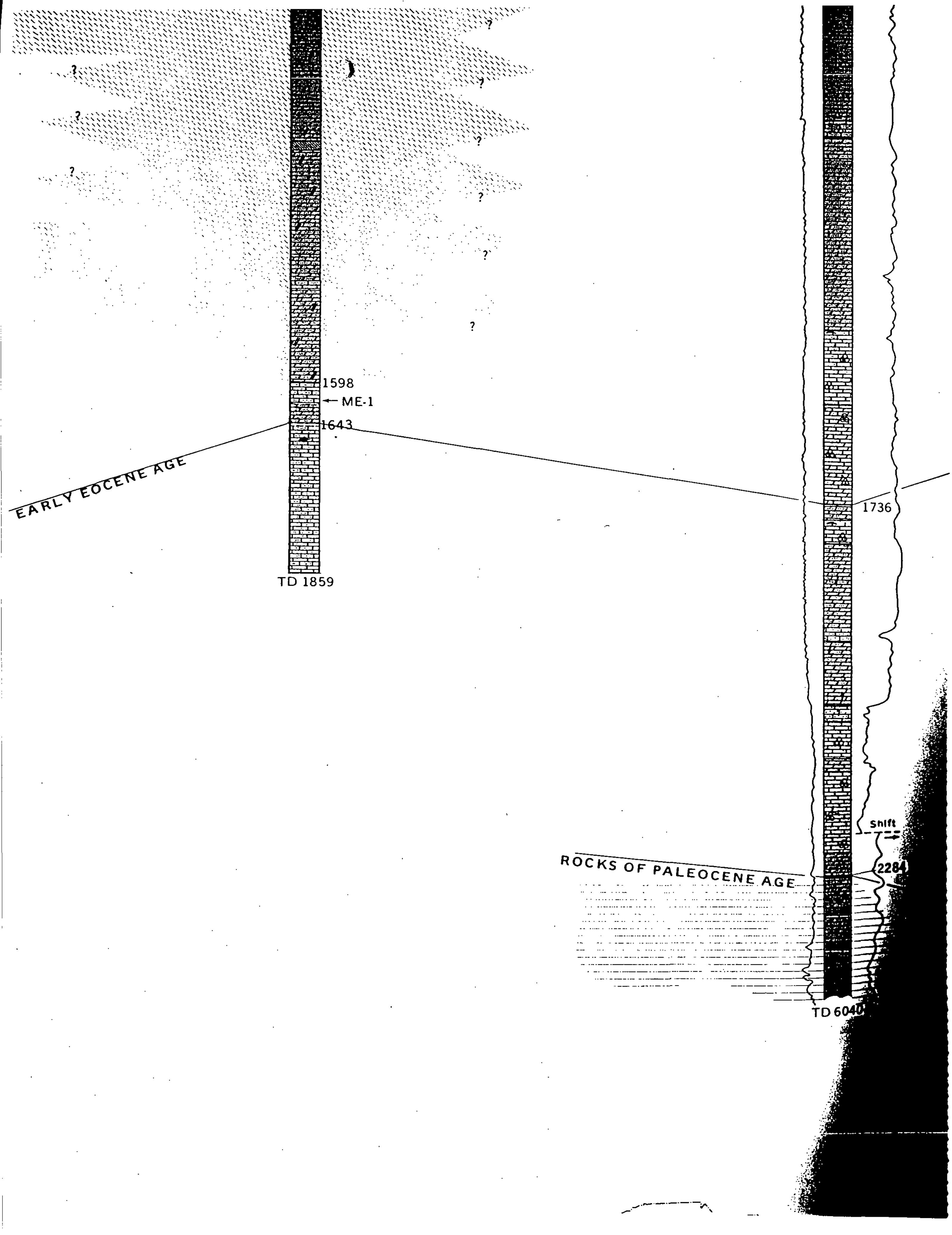
383
1005
POST-MIOCENE ROCKS
CKS OF LATE EOCENE
OF MIDDLE EOCENE AGE



1598
ME-1
1643
EARLY EOCENE AGE
TD 1859
1736
Shift
2284
ROCKS OF PALEOCENE AGE
TD 6040

EXPLANATION

Rock Types

- Sand
- Interbeded sand and clay
- Sandy clay
- Dolomite
- Sandy dolomite
- Clayey dolomite
- Limestone
- Sandy limestone
- Clayey limestone
- Dolomitic limestone
- Evaporite
- No sample

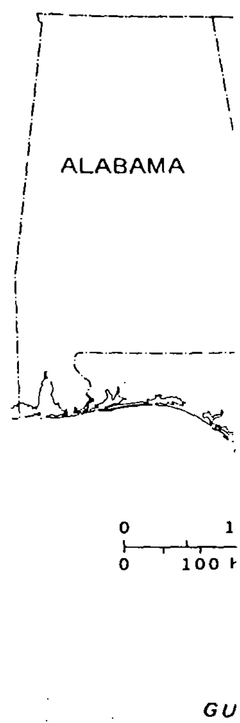
Accessories

- Microfossils
- Macrofossils
- Glauconite
- *P* Phosphate
- *L* Carbonaceous material
- Chert
- Intergranular gypsum
- UE-4 Index fossil occurance (see table 1)

Hydrologic Units

High-permeability units are unpatterned

- Upper confining unit of the Floridan aquifer system
- II Confining unit of subregional extent within the Floridan aquifer system (Roman numerals keyed to text)
- Local confining unit within the Floridan aquifer system
- Lower confining unit of the Floridan aquifer system



Index map showing l
See Plate 1 for speci

ydrologic cross-section G-G′ from E. C. Wright well 1, Pinellas County, Florida,

Reference 15

STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Tom Gardner, *Executive Director*

DIVISION OF RESOURCE MANAGEMENT
Jeremy A. Craft, *Director*

FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist*

BULLETIN NO. 59

THE LITHOSTRATIGRAPHY OF THE HAWTHORN GROUP (MIOCENE) OF FLORIDA

By
Thomas M. Scott

Published for the
FLORIDA GEOLOGICAL SURVEY
TALLAHASSEE
1988

DEPARTMENT
OF
NATURAL RESOURCES

DEPARTMENT
OF
NATURAL RESOURCES

LETTER OF TRANSMITTAL

Bureau of Geology
August 1988

Governor Bob Martinez, Chairman
Florida Department of Natural Resources
Tallahassee, Florida 32301

Dear Governor Martinez:

The Florida Geological Survey, Bureau of Geology, Division of Resource Management, Department of Natural Resources, is publishing as its Bulletin No. 59, *The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida.* This is the culmination of a study of the Hawthorn sediments which exist throughout much of Florida. The Hawthorn Group is of great importance to the state since it constitutes the confining unit over the Floridan aquifer system. It is also of economic importance to the state due to its inclusion of major phosphorite deposits. This publication will be an important reference for future geological investigations in Florida.

Respectfully yours,

Walter Schmidt, Chief
Florida Geological Survey

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APPENDIX

FIGURES

TABLE

ABSTRACT

The Hawthorn Formation has been a problematic unit for geologists since its inception by Dall and Harris (1892). It is a complex unit consisting of interbedded and intermixed carbonate and siliciclastic sediments containing varying percentages of phosphate grains. These sediments have been widely studied by geologists due to their economic and hydrologic importance in the southeastern United States. Economically, the Hawthorn sediments contain vast quantities of phosphate and clay and limited amounts of uranium. Hydrologically, the Hawthorn contains secondary artesian aquifers, provides an aquiclude for the Floridan aquifer system and, in some ares, makes up the upper portion of the Floridan aquifer system.

The Hawthorn Formation of previous investigators has been raised to group status in Georgia by Huddlestun (in press). The present investigation extends the formations recognized in southern Georgia into northern Florida with some modifications, and accepts Huddlestun's concept of the Hawthorn Group. The Hawthorn Group and its component formations in southern Florida represent a new lithostratigraphic nomenclature applied to these sediments. The elevation of the Hawthorn to group status in Florida is justified by the Hawthorn's complex nature and the presence of areally extensive, mappable lithologic units.

The Hawthorn Group in northern peninsular Florida consists of, in ascending order, the Penney Farms Formation, the Marks Head Formation and the Coosawhatchie Formation. The Coosawhatchie Formation grades laterally and, in a limited area, upwards into the Statenville Formation.

Lithologically, the Hawthorn Group in northern Florida is made up of a basal carbonate with interbedded siliciclastics (Penney Farms), a complexly interbedded siliciclastic-carbonate sequence (Marks Head), a siliciclastic unit with varying percentages of carbonate in both the matrix and individual beds (Coosawhatchie) and a crossbedded, predominantly siliciclastic unit (Statenville). Phosphate grains are present throughout these sediments, varying in percentage up to 50 percent of the rock.

Sediments of the Hawthorn Group in northern peninsular Florida range in age from Early Miocene (Aquitanian) to Middle Miocene (Serravalian). This represents a significant extension of the previously accepted Middle Miocene age.

In southern Florida, the group includes two formations, in ascending order, the Arcadia Formation and the Peace River Formation. The Tampa Formation or Limestone of former usage is included as a lower member of the Arcadia Formation due to the Tampa's limited areal extent, lithologic similarities, and lateral relationship with the undifferentiated Arcadia. Similarly, the Bone Valley Formation of former usage is incorporated as a member in the Peace River Formation.

Lithologically, the Arcadia Formation is composed of carbonate with varying amounts of included and interbedded siliciclastics. Siliciclastic sediments in the Arcadia are most prevalant in its basal Nocatee Member. The Peace River Formation is predominantly a siliciclastic unit with some interbedded carbonates. Phosphorite gravel is most common in the Bone Valley Member. Sand-sized phosphate grains are virtually ubiquitous in the southern Florida sediments with the exception of the Tampa Member where it is often absent.

The southern Florida Hawthorn sediments range in age from Early Miocene (Aquitanian) to Early Pliocene (Zanclian).

The Hawthorn Group in the eastern Florida panhandle is composed of the Torreya Formation and, in a few areas, a Middle (?) Miocene unnamed siliciclastic unit. Lithologically, the Torreya consists of a carbonate-rich basal section with interbedded clays and sands, and a dominantly siliciclastic, often massive, plastic clayey upper unit (Dogtown Member). Phosphate grains are noticeably less common in the Hawthorn of the panhandle.

Hawthorn Group sediments are characterized by the occurrence of an unusual suite of minerals. Apatite (phosphate grains) is virtually ubiquitous in the peninsular Hawthorn sediments. Palygorskite, sepiolite and dolomite occur throughout the group statewide.

Miocene sea level fluctuations were the primary controlling factor determining the extent of Hawthorn deposition in Florida. During the maximum Miocene transgression, sediments of the Hawthorn Group

were probably deposited over the entire Florida platform. Hawthorn sediments were subsequently removed from the crest of the Ocala Platform (Ocala Uplift) and the Sanford High by erosion.

The Hawthorn Group appears to have been deposited under shallow marine conditions. These conditions are suggested by the occurrence of molds of shallow water mollusks and a limited benthic foraminifera fauna. The deepest water conditions apparently existed in the Jacksonville and Okeechobee Basins.

The gamma-ray signature of the Hawthorn Group is quite distinctive, providing a useful tool for identification and correlation in areas of limited data. The Hawthorn signature consists of distinctly different patterns in northern and southern peninsular and eastern panhandle Florida.

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THE LITHOSTRATIGRAPHY OF THE HAWTHORN GROUP (MIOCENE) OF FLORIDA

By
Thomas M. Scott

INTRODUCTION

The late Tertiary (Miocene-Pliocene) stratigraphy of the southeastern Coastal Plain provides geologists with many interesting and challenging problems. Much of the interest has been generated by the occurrence of scattered phosphorite from North Carolina to Florida. The existence of phosphate in the late Tertiary rocks of Florida was recognized in the late 1800's and provided an impetus to investigate these sediments. More recently, the hydrologic importance of these units has led to further investigations of the stratigraphy and lithology to determine their effectiveness as an aquiclude, aquitard and aquifer.

The Hawthorn Formation in Florida has long been a problematic unit. Geologists often disagree about the boundaries of the formation. The resulting inconsistencies have rendered accurate correlation between authors virtually impossible.

The biggest problem hindering the investigation of the Hawthorn strata has been a paucity of quality subsurface data. Since the mid-1960's, the Florida Geological Survey has been gathering core data from much of the state, providing a unique opportunity to investigate the extent of, and facies relationships in the Hawthorn of the subsurface.

This investigation is an attempt to provide an understanding of the Hawthorn Group, its lithologies, stratigraphy and relation to subjacent and suprajacent units. A greater understanding of the Hawthorn is imperative to deciphering the late Tertiary geologic history of Florida.

PURPOSE AND SCOPE

The purpose of this investigation is to provide a coherent lithostratigraphic framework facilitating a better understanding of the Hawthorn Group in Florida. The internal framework of the Hawthorn, its lateral continuity, and relation to subjacent and suprajacent units were investigated in order to provide this knowledge.

The area covered by this study extends from the Apalachicola River in the Florida Panhandle on the west to the Atlantic Coast on the east and from the Georgia-Florida border on the north, south to the Florida Keys (Figure 1). The study area encompasses all or portions of 56 counties. Data points outside the study area, particularly in Georgia, were used to assist in providing a more accurate picture within the study area boundaries.

The study area boundaries were chosen based on several criteria. In the past, the western limits of the Hawthorn were drawn at the Apalachicola River. The western boundary was chosen both to coincide with the historical boundary and to avoid overlap with the investigation of equivalent sediments in the Apalachicola Embayment by Schmidt (1984).

More than 100 cores provided the data base for the present study. The locations of cored data points are shown on Figure 2. Figure 3 delineates cross section transects.

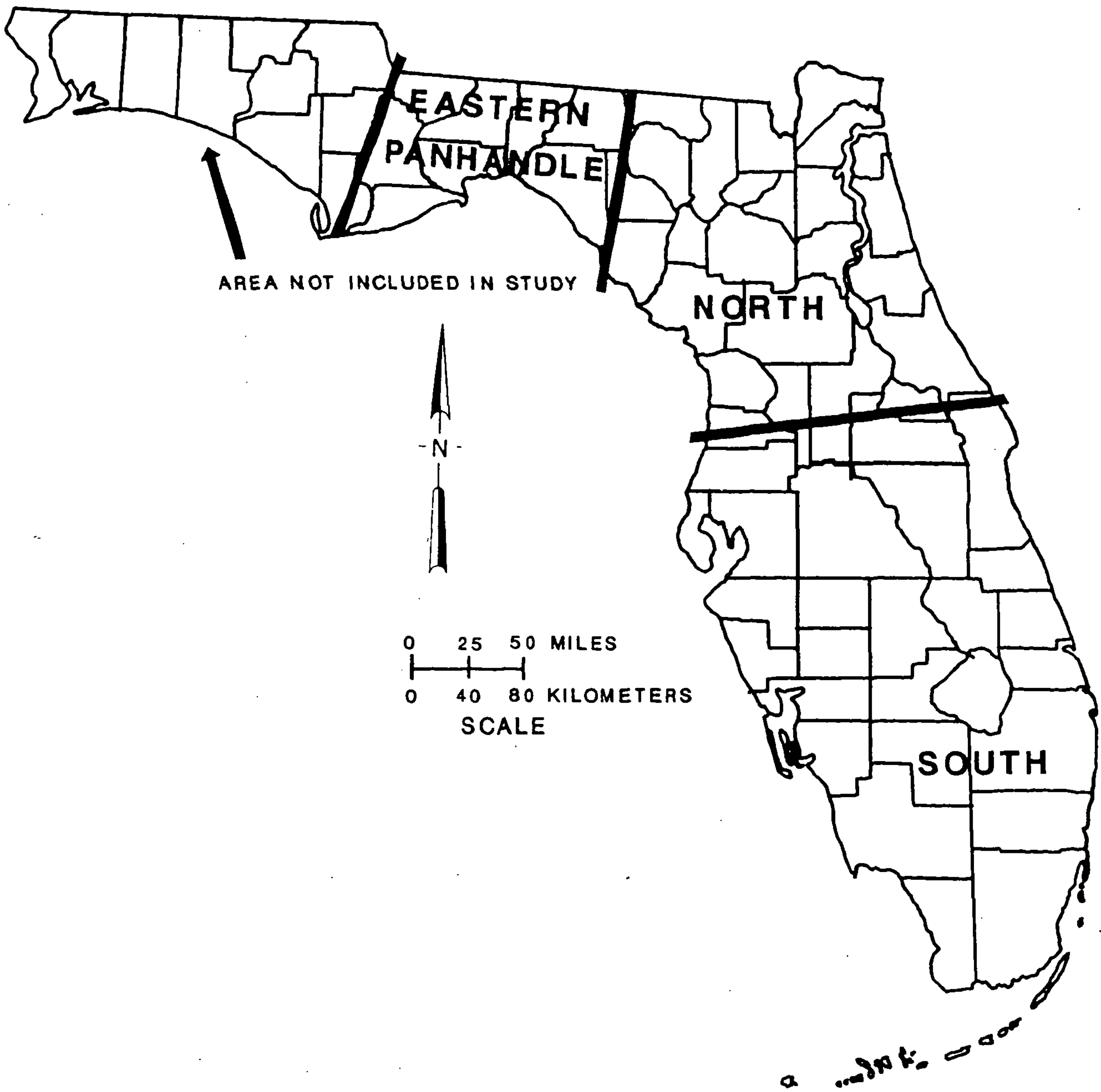


Figure 1. Study area and areas of discussion.

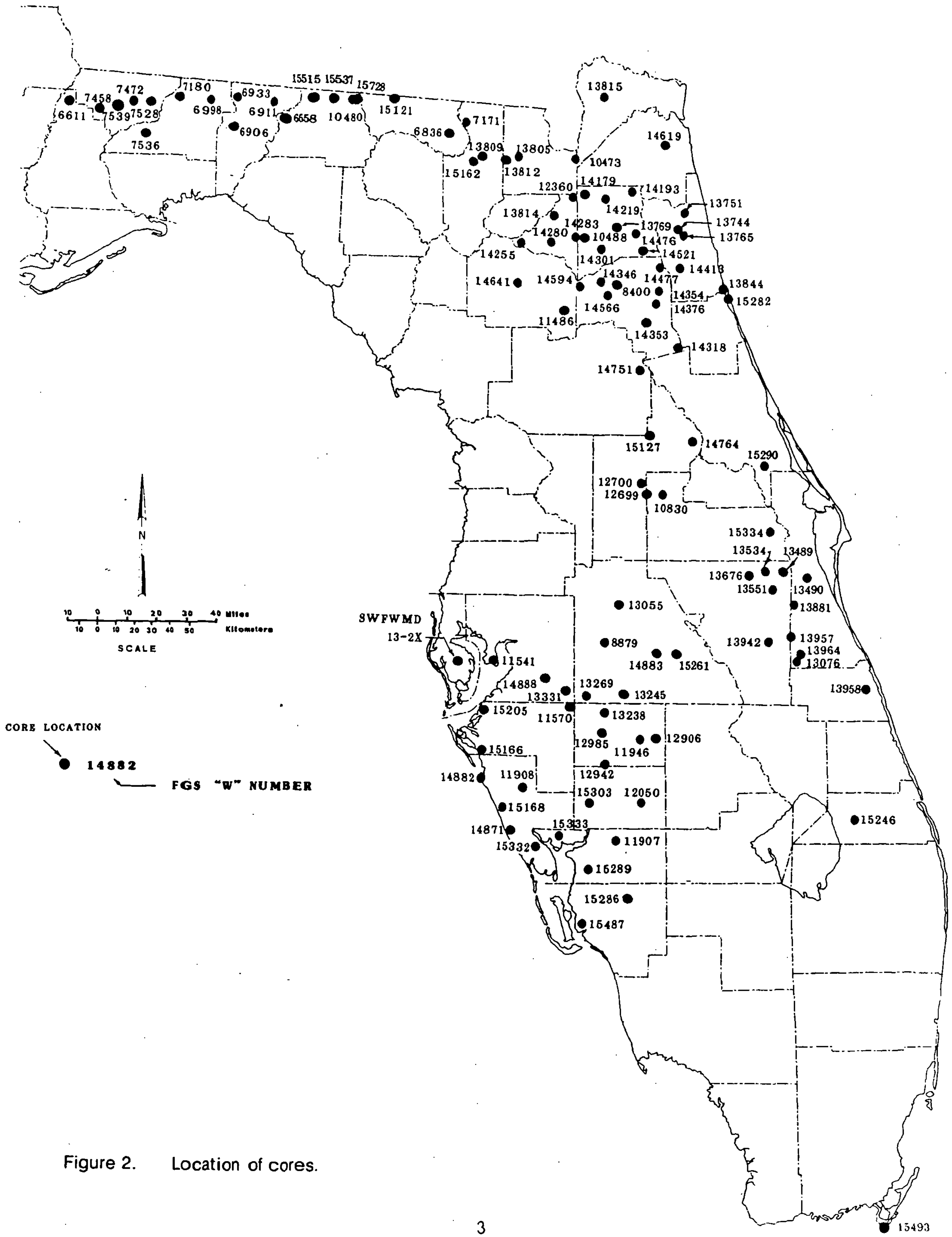


Figure 2. Location of cores.

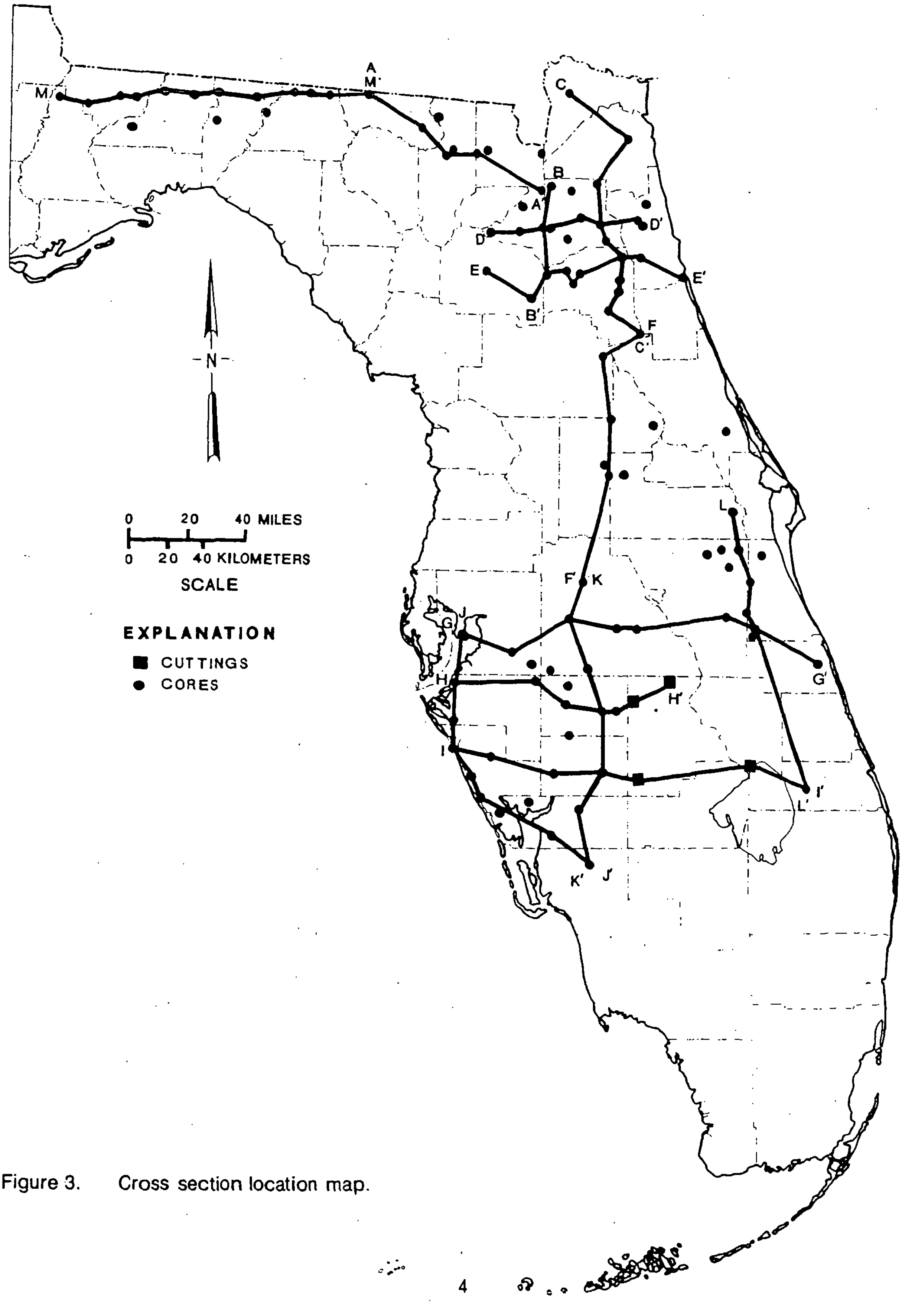


Figure 3. Cross section location map.

METHOD OF INVESTIGATION

The Hawthorn Group is predominantly a subsurface unit. As a result, the principal data sources for this study were the cores drilled by the Florida Geological Survey from 1964 through the present. The cores were obtained using a Failing 1500 Drillmaster with a capacity to drill in excess of 1000 feet (305 meters). Under most conditions, nearly continuous recovery of 1-¾ inch (4.5 cm) diameter cores was obtained. Losses in core recovery were minimized due to the expertise of driller Justin Hodges. The cores recovered were placed in boxes and are stored at the Geological Survey in Tallahassee. Additional cores were obtained from the Southwest Florida Water Management District and the St. Johns River Water Management District. All cores are available for inspection by the public.

Supplemental lithologic data sources included samples obtained from water wells drilled by private contractors who provide cuttings to the Geological Survey. Unfortunately, the cuttings do not necessarily provide accurate lithologic information. This circumstance is due to the loss of fine grained (clay, silt and very fine sand-sized), poorly consolidated to nonindurated sediments. The drilling method, sample collection, and subsequent removal of drill mud by washing facilitates the loss of this material. The net result is to skew the sediment types toward sands and more indurated materials. The use of cuttings does, however, allow the extrapolation of lithologies and contacts in areas of limited core control. Water-well cuttings were thus used only to supplement core data.

All cores and well cuttings were examined using a binocular microscope. Examinations were normally made at magnification of 10x to approximate the use of a hand lens in field indentification. Higher magnifications (up to 45x) were employed for the identification of the finer grained constituents of the sediments. Geologist's logs of the samples were recorded according to the Florida Geological Survey format which aids in producing a concise, standardized lithologic description. Coded lithologic data were stored on magnetic tape for later retrieval and use. These data were run through the Florida Geological Survey's FBGO1 program on the Florida State University computer which provided a full English printout of the lithologic information. The data were also run through the Stratlog program to provide a lithologic column of each core analyzed.

Samples collected for x-ray analysis were taken primarily from cores, although outcrops along the Suwannee and Alapaha Rivers were also sampled. Since clay minerals present in the sediments were of primary interest, samples were taken from the more clayey portions of the cores. Samples were mounted for x-ray analysis by standard techniques and analyzed with CuKα radiation.

Gamma-ray logs were run on most core holes. Numerous gamma-ray logs run in water wells are also available for correlation purposes. All geophysical logs are on permanent file at the Geological Survey and are open to the public.

PREVIOUS INVESTIGATIONS

Interest in the general stratigraphic framework of the southeastern Coastal Plain and the occurrence of phosphate in the sediments now assigned to the Hawthorn Group prompted geologists to investigate these sediments in Florida. Table 1 indicates the important nomenclatural changes that have occurred in relation to the Hawthorn Group.

The discovery of phosphatic rock in Florida first occurred in the late 1870's near the town of Hawthorne in Alachua County (Day, 1886). By 1883, Dr. C.A. Simmons quarried and ground the phosphatic rocks for fertilizer (Sellards, 1910). During the 1880's phosphate was also discovered in central Florida.

Smith (1881) noted the phosphatic rocks exposed along the Suwannee River from the Okefenokee Swamp downstream and placed them in the Vicksburg Stage. Hawes (1882), in discussing the "phosphatic sandstones from Hawthorne," described them as containing sharks' teeth and bones belonging to the Tertiary Age. Smith (1885) and Johnson (1885) discussed the stratigraphy and occurrence of the phosphatic rocks of Florida. Johnson (1885) applied the name Fort Harlee marl to the phosphatic sediments at Waldo in Alachua County. He mentioned the occurrence of *Ostrea* and silicified corals within the sediments. Johnson also mentioned that those rocks are rather widespread in the state.

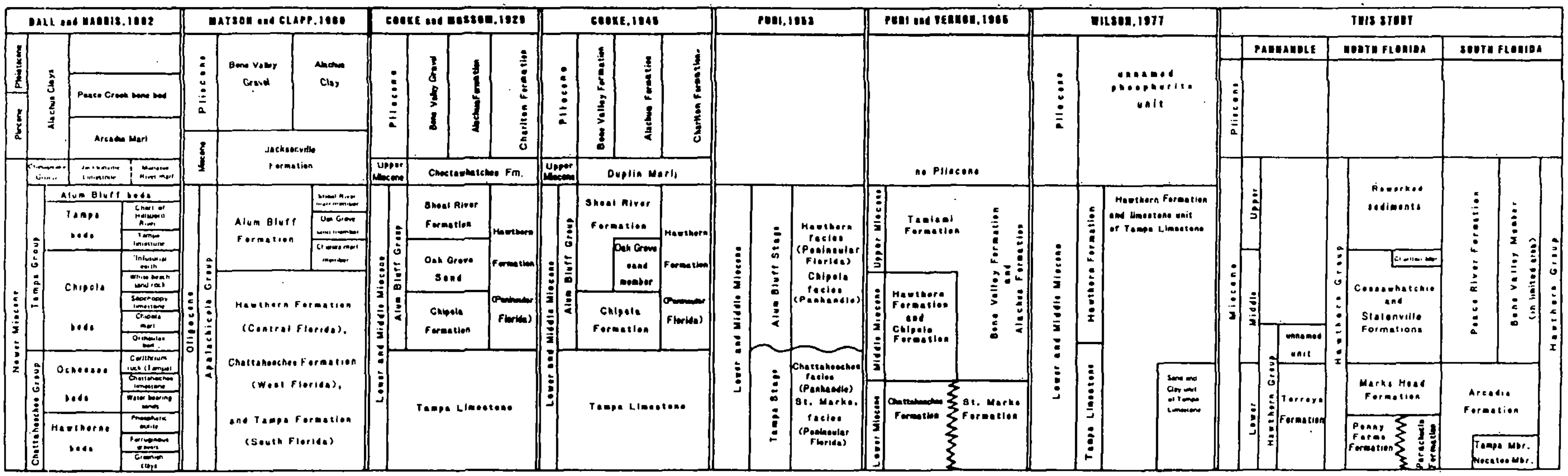


Table 1. Nomenclatural changes that have occurred in relation to the Hawthorn Group.

Smith (1885) examined samples sent to him by L.C. Johnson and thought the phosphatic limestone at Hawthorne was Eocene or Oligocene, as was the rest of the limestone in the peninsula. However, fossiliferous samples from the Waldo area indicated to Smith that the rocks were Miocene. He considered the rocks near Waldo to be the same as those exposed at Rock Springs in Orange County. Kost (1887), in the first report of the Florida Geological Survey, mentioned the recognition of phosphatic rocks in several locations throughout the state. Penrose (1888) briefly discussed the phosphatic sediments of Alachua County. Johnson (1888) named the Waldo Formation for the phosphatic sediments exposed in eastern Alachua County.

The first major contribution to the understanding of the Miocene phosphatic sediments of Flordia was published by Dall and Harris (1892). Relying upon unpublished data from L.C. Johnson and their own field information, Dall and Harris applied the name "Hawthorne beds" for the phosphatic sediments exposed and quarried near Hawthorne, Alachua County. They reproduced sections and descriptions obtained from Johnson. Dall and Harris placed the "Hawthorne beds" in the "newer" Miocene. Johnson's Waldo Formation was thought to be in the "older" Miocene although Dall and Harris state (p. 111), "Old Miocene phosphatic deposits - These rocks were among those referred by Johnson to his Waldo formation, though typical exposures at Waldo belong to the newer or Chesapeake Miocene." Dall and Harris placed the "Hawthorne beds" in their "Chattahoochee group" which overlies the Vicksburg Group and underlies the "Tampa group" (including their "Tampa limestone" which they felt was younger than the "Hawthorne beds").

The name "Jacksonville limestone" was applied by Dall and Harris (1892) to a "porous, slightly phosphatic, yellowish rock" first recognized by Smith (1885). They thought the "Jacksonville limestone" covered a large area from Duval County to at least Rock Springs in Orange County and included it in the "newer Miocene" above the "Hawthorne beds."

Dall and Harris (1892) examined the sediments in the phosphate mining area on the Peace River and referred to the phosphate-producing horizon as the "Peace Creek bone bed." Underlying the producing zone was a "yellowish sandy marl" containing phosphate grains and mollusk molds which they named the "Arcadia marl." Both units were considered to be Pliocene in age.

Dall and Harris also named the "Alachua clays" stating these clays "occur in sinks, gullies, and other depressions... ." They assigned the Alachua clays to the Pliocene based on vertebrate remains.

Matson and Clapp (1909) considered the Hawthorn to be Oligocene following Dall (1896) who began referring to the "older Miocene" as Oligocene. They considered the Hawthorn to be contemporaneous with the Chattahoochee Formation of west Florida and the Tampa Formation of south Florida. The Hawthorn was referred to as a formation rather than "beds" without formally making the change or designating a type section. Matson and Clapp placed the Hawthorn in their "Apalachicola group." Chert belonging to the "Suwannee limestone" was also included in the Hawthorn Formation at this time.

Matson and Clapp (1909) named the "Bone Valley gravel," replacing the "Peace Creek bone bed" of Dall and Harris (1892). They believed, as did Dall and Harris, that this unit was Pliocene. Matson and Clapp thought that the Bone Valley was predominantly of fluviatile origin and was derived from preexisting formations, especially the "Hawthorn formation." The Bone Valley gravels were believed to be younger than Dall and Harris' "Arcadia marl," older than the Caloosahatchee marl and in part contemporaneous with the "Alachua clays."

Veatch and Stephenson (1911) did not use the term "Hawthorn formation" in describing the sediments in Georgia. Instead the sediments were included in the "Alum Bluff formation" and described as strata lying between the top of the Chattahoochee formation and the base of the Miocene. Overlying their "Alum Bluff" sediments was an argillaceous sand that was in places a friable phosphatic sand which Veatch and Stephenson named the Marks Head marl. The Duplin marl, a coarse phosphatic sand with shells, overlies the Marks Head or the Alum Bluff when the Marks Head is absent.

Sellards (1910, 1913, 1914, 1915) discussed the lithology of the sediments associated with hard rock and pebble phosphate deposits. He presented a review of the origins of the phosphate and their relation to older formations. Sellards (1915) published the section exposed at Brooks Sink in a discussion of the incorporated pebble phosphates.

Matson and Sanford (1913) dropped the "e" from the end of Hawthorne (as Dall and Harris had used it). They state (p. 64), "The name of this formation is printed on the map as Hawthorne, the spelling used in some previously published reports, but as the geographic name from which it is derived is spelled Hawthorn, the final "e" has been dropped in the text." This began a debate of minor importance that continues to the present. Currently the Florida Geological Survey accepts the name without the "e."

Vaughan and Cooke (1914) established that the Hawthorn is not equivalent to or contemporaneous with, any part of the Chattahoochee Formation but is essentially equivalent to the "Alum Bluff formation." They suppressed the name Hawthorn and recommended the use of the name "Alum Bluff formation" and retained the Oligocene age.

Matson (1915) believed that the "Alum Bluff" (Hawthorn) phosphatic limestones formed the bed rock beneath the pebble phosphates of central Florida. This unit had previously been called the "Arcadia marl" (Dall and Harris, 1892). Matson added the sands of the "Big Scrub" in what is now the Ocala National Forest and the sands of the ridge west of Kissimmee (Lake Wales Ridge) to the "Alum Bluff formation." He thought also that the sequence of sediments called the "Jacksonville formation" (formerly the "Jacksonville limestone" of Dall and Harris, 1892) contained units equivalent to the "Alum Bluff formation." Matson thought that the "Bone Valley gravel" and "Alachua clays" were Miocene. He based this on the belief that the elevation of the "Bone Valley gravel" was too high to be Pliocene.

Sellards (1919) considered the "Alum Bluff" to be Miocene rather than Oligocene based on the vertebrate and invertebrate faunas. He stated (p. 294): "In the southern part of the state the deposits which are believed to represent the equivalent of the Alum Bluff formation are distinctly phosphatic." He felt that the deposits referred to the "Jacksonville formation" are lithologically similar to the "Alum Bluff" sediments as developed in south Florida and contain similar phosphatic pebbles. According to Sellards (1919), phosphate first appears in the Miocene "Alum Bluff" rocks, and the "Bone Valley gravels" and the "Alachua clays" represent the accumulation of reworked Miocene sediments.

Mossom (1925, p. 86) first referred the "Alum Bluff" to group status citing "The Alum Bluff is now considered by Miss Gardner as a group... ." Gardner did not publish this until 1926. Gardner (1926), in raising the Alum Bluff to a group, also raised the three members, Shoal River, Oak Grove, and Chipola, to formational status. Mossom (1926) felt the Chipola Formation was the most important and widespread subdivision of the group. He included the fuller's earth beds in north Florida and the phosphatic sands throughout the state in this formation. However, the phosphatic sands were generally referred simply to the Alum Bluff Group. Mossom also believed that the red, sandy clay sediments forming the hills in north Florida belonged in the Chipola Formation.

The Hawthorn Formation was reinstated by Cooke and Mossom (1929), since Gardner (1926) had raised the Alum Bluff to group status. Cooke and Mossom (1929) defined the Hawthorn Formation to include the original Hawthorn "beds" of Dall and Harris (1892) excluding the "*Cassidulus*-bearing limestones" and chert which Matson and Clapp (1909) had placed in the unit. Cooke and Mossom believed the "*Cassidulus*-bearing limestones" and the chert should be placed in the Tampa Limestone (which at that time included strata now assigned to the Suwannee Limestone). They included the "Jacksonville limestone" and the "Manatee River marl" (Dall and Harris, 1892) in the Hawthorn even though they felt the faunas may be slightly younger than typical Hawthorn. They also included Dall and Harris' "Sopchoppy limestone" in the Hawthorn. Cooke and Mossom felt that a white to cream-colored, sandy limestone with brown phosphate grains was the most persistent component of this unit.

Stringfield (1933) provided one of the first, although brief, descriptions of the Hawthorn Formation in central-southern Florida. He noted that the Hawthorn contained more limestone in the lower portion toward the southern part of his study area.

Cooke (1936) extended the Hawthorn Formation as far northeastward as Berkeley County, South Carolina. Cooke (1943, p. 90) states, "The Hawthorn Formation underlies an enormous area that stretches from near Arcadia, Florida, to the vicinity of Charleston, South Carolina." Cooke (1945) discussed the Hawthorn and its occurrence in Florida. The only change suggested by Cooke (1945, p. 192) was to tentatively include the Jacksonville Formation of Dall and Harris (1892) into the Duplin Marl rather than in the Hawthorn as Cooke and Mossom (1929) had done. Cooke (1945) also believed that the Apalachicola

River was the western boundary of the Hawthorn.

Parker and Cooke (1944) investigated the surface and shallow subsurface geology of southernmost Florida. The plates accompanying their report showed the Hawthorn Formation ranging from -10 feet MSL (-3 meters) to -120 feet MSL (-37 meters) overlain by the Tamiami Formation, Caloosahatchee Marl, and Buckingham Marl. Parker (1951) reassigned the upper sequence of Hawthorn sediments to the Tamiami Formation based on his belief that the fauna was Late Miocene rather than Middle Miocene. This significantly altered the concept of Mansfield's (1939) Tamiami Limestone and of the Hawthorn in southern Florida. Parker et al. (1955) continued this concept of the formations.

Cathcart (1950) and Cathcart and Davidson (1952) described the Hawthorn phosphates, their relationship to the enclosing sediments and the lithostratigraphy. Also mentioned is the variation in lithologies and thickness of the Hawthorn within the land pebble district. An excellent description of the Bone Valley Formation was presented by Cathcart (1950).

Vernon (1951) published a very informative discussion of the Miocene sediments and associated problems. Beyond providing data on the limited area of Citrus and Levy Counties, Vernon provided a proposed geologic history of Miocene events. He believed that the Alachua Formation was a terrestrial facies of the Hawthorn and also was, in part, younger than Hawthorn.

Puri (1953) in his study of the Flordia panhandle Miocene referred to the Middle Miocene as the Alum Bluff Stage. He considered the Hawthorn to be one of the four lithofacies of the Alum Bluff Stage.

Yon (1953) investigated the Hawthorn between Chattahoochee in the panhandle and Ellaville on the Suwannee River. Yon included in the Hawthorn the sand and clay unit that was later formally placed in the Miccosukee by Hendry and Yon (1967).

Bishop (1956), in a study of the groundwater and geology of Highlands County, Florida, concluded that the "Citronelle" sands which overlie the Hawthorn graded downward into the Hawthorn. He suggested that these sands be included in the Hawthorn as a non-marine, continental facies deposited as a delta to a large river which existed in Florida during the Miocene.

Pirkle (1956 a, 1956 b, 1957) discussed the sediments of the Hawthorn Formation from Alachua County, Florida. He considered the Hawthorn as a unit of highly variable marine sediments which locally contained important amounts of phosphate. He also regarded the sediments of the Alachua Formation as terrestrial reworked sediments ranging from Lower Miocene to Pleistocene. Later studies by Pirkle, Yoho, and Allen (1965) and Pirkle, Yoho, and Webb (1967) characterized the sediments of the Hawthorn and Bone Valley Formations.

The interest of the United States Geological Survey in the Hawthorn and Bone Valley Formations for their economic deposits of phosphate and related uranium concentrations resulted in a number of publications including Bergendal (1956), Espenshade (1958), Carr and Alverson (1959), Cathcart and McGreevy (1959), Ketner and McGreevy (1959), Cathcart (1963 a, b; 1964; 1966), Espenshade and Spencer (1963), and Altschuler, Cathcart, and Young (1964). With the exception of Espenshade (1958) and Espenshade and Spencer (1963), the studies investigated the strata in the Central Florida Phosphate District and adjacent areas. Espenshade (1958) and Espenshade and Spencer (1963) conducted investigations in north Florida.

Goodell and Yon (1960) provide a discussion of the lithostratigraphy of the post-Eocene rocks from much of the state. They provide a regional lithostratigraphic view of the Miocene sediments in Florida.

The occurrence of magnesian (Mg) rich clays (palygorskite) within the Hawthorn Formation has been investigated by several authors. McClellan (1964) studied the petrology and occurrence of the palygorskite (attapulgite). Gremillion (1965) investigated the origin of the clays. Ogden (1978) suggested depositional environments and the mode of formation of the clays.

Puri and Vernon (1964) summarized the geology of the Hawthorn. They discussed the status of the knowledge of the Hawthorn but added very little new information.

Brooks (1966, 1967) suggested that the Hawthorn should be raised to group status in the future. He further discussed the existence of the Hawthorn across the Ocala Uplift and its subsequent erosional removal. Brooks believed Middle Miocene strata were absent from the Ocala Uplift but were present downdip from the arch. He felt that Lower Miocene beds were present on the arch.

Sever, Cathcart, and Patterson (1967) investigated the phosphate resources and the associated stratigraphy of the Hawthorn Formation in northern Florida and southern Georgia.

Riggs (1967) suggested raising the Hawthorn Formation to group status based on his research in the phosphate district. The rocks of Riggs' "Hawthorn group" were related by containing greater than one percent phosphate grains. The Bone Valley Formation was included as the uppermost unit of the group. Riggs and Freas (1965) and Freas and Riggs (1968) also discussed the stratigraphy of the central Florida phosphate district and its relation to phosphorite genesis.

The geology and geochemistry of the northern peninsular Florida phosphate deposits were investigated by Williams (1971). Clark (1972) investigated the stratigraphy, genesis and economic potential of the phosphorites in the southern extension of the Central Florida Phosphate District.

Weaver and Beck (1977) published a wide ranging discussion of the Coastal Plain Miocene sediments in the southeast. Emphasis was placed on the depositional environments and the resulting sediments, particularly the clays.

Wilson (1977) mapped the Hawthorn and part of the Tampa together. He separated the upper Tampa, termed the Tampa Limestone unit, from the lower "sand and clay" unit of the Tampa Limestone.

Missimer (1978) discussed the Tamiami-Hawthorn contact in southwest Florida and the inherent problems with the current stratigraphic nomenclature. Peck et al. (1979) believed that the definition of the Tamiami by Parker et al. (1955) added to the previously existing stratigraphic problems. Hunter and Wise (1980 a, 1980 b) also addressed this problem suggesting a restriction and redefinition of the Tamiami Formation.

King and Wright (1979) in an effort to alleviate some of the stratigraphic problems associated with the Tampa and Hawthorn formations redefined the Tampa and erected a type section from a core at Ballast Point. Their redefinition restricted the Tampa to the quartz sandy carbonates with greater than 10 percent quartz sand and less than 1 percent phosphate grains. King (1979) presented a discussion of the previous investigations of the Tampa to which the reader is referred. The discussion is not repeated here.

Riggs (1979 a, 1979 b; 1980) described the phosphorites of the Hawthorn and their mode of deposition. Riggs (1979 a) suggested a model for phosphorite sedimentation in the Hawthorn of Florida.

Scott and MacGill (1981) discussed the Hawthorn Formation in the Central Florida Phosphate District and its southern extension. Scott (1983) provided a lithostratigraphic description of the Hawthorn in northeast Florida. Both studies were in cooperation with the United States Bureau of Mines.

T.M. Scott (1981) suggested the Hawthorn Formation had covered much of the Ocala Arch and was subsequently removed by erosion. Scott (1982) designated reference cores for the Hawthorn Formation and compared these to the reference localities previously designated. Scott's (1982) discussion was limited to the northeastern part of the state.

Cyclic sedimentation in the sediments of the Hawthorn was proposed by Missimer and Banks (1982). Their study suggested that reoccurring sediment groups occurred within the formation in Lee County. Also Missimer and Banks followed the suggestions of Hunter and Wise (1980 a, 1980 b) in restricting the definition of the Tamiami. This is also the case in Wedderburn et al. (1982).

Hall (1983) presented a description of the general geology and stratigraphy of the Hawthorn and adjacent sediments in the southern extension of the Central Florida Phosphate District. An excellent discussion of the stratigraphy and vertebrate paleontology of this area was provided by Webb and Crissinger (1983).

Silicification of the Miocene sediments in Florida has been the focus of a number of studies. Strom, Upchurch and Rosenweig (1981), Upchurch, Strom and Nuckles (1982), and McFadden, Upchurch, and Strom (1983) discussed the origin and occurrence of the opaline cherts in Florida. Related to the cherts are palygorskite clays that were also discussed in these papers and by Strom and Upchurch (1983, 1985).

There have been a number of theses completed on various aspects of the Hawthorn Group. These include McClellan (1962), Reynolds (1962), Isphording (1963), Mitchell (1965), Assefa (1969), Huang (1977), Liu (1978), King (1979), Reik (1980), Leroy (1981), Peacock (1981), and McFadden (1982).

Many water resource investigations include a section on the Hawthorn Formation but do not add new geologic or stratigraphic data. These are not included here.

GEOLOGIC STRUCTURE

The geologic structures of peninsular Florida have played an important role in the geologic history of the Hawthorn Group. These features affected the depositional environments and the post-depositional occurrence of the Hawthorn sediments. Due to the nature of the Tertiary sediments in peninsular Florida, it is difficult to ascertain a true structural origin for some of these features. Depositional and erosional processes may have played a role in their development.

The most prominent of the structures in peninsular Florida is the Ocala Platform (often referred to as Ocala Arch or Uplift) (Figure 4). The term platform rather than uplift or arch is preferred here since it does not have a structural connotation.

Originally named the Ocala Uplift by O.B. Hopkins in a 1920 U.S. Geological Survey press release, this feature was formally described by Vernon in 1951. Vernon described it as a gentle flexure developed in Tertiary sediments with a northwest-southeast trending crest. He believed that the crest of the platform has been flattened by faulting. Vernon (1951) dated the formation of the uplift as being Early Miocene based on the involvement of basal Miocene sediments in the faulting and the wedging out of younger Miocene sediments against the flanks of the platform. Cooke (1945) thought that warping began prior to the Late Eocene and continued into the Late Miocene or later. Ketner and McGreevy (1959) suggested that the platform formed prior to Late Miocene since undeformed beds of Late Miocene overlie warped beds of the Ocala Platform. Cooke (1945), Espenshade and Spencer (1963) and T.M. Scott (1981) believed that the Hawthorn once covered most or all of the Ocala Platform. Vernon (1951) believed the Platform was an island area throughout much of the Miocene and the Hawthorn sediments did not extend across the structure. Brooks (1966) believed the feature formed prior to the early Late Miocene. He also agrees with Pirkle (1956 b) that the Hawthorn once extended across the platform.

Riggs (1979 a, b) stated that the Ocala Upland (his term for the Ocala Platform) was a major structural feature controlling the formation and deposition of the phosphorites in the Florida Miocene.

The Sanford High is another important positive feature in the northern half of peninsular Florida (Figure 4). Vernon (1951) proposed the name for a feature located in Seminole and Volusia Counties, Florida. He describes the feature as "a closed fold that has been faulted, the Sanford High being located on the upthrown side." The Hawthorn Group and the Ocala Group are missing from the crest of the Sanford High. The Avon Park Formation lies immediately below post-Hawthorn sediments. The missing section presumably was removed by erosion. Meisburger and Field (1976), using high-resolution seismic reflection profiling, identified a structural high offshore from Daytona Beach in Volusia County and suggested that this feature may be an offshore extension of the Sanford High. Meisburger and Field believed that the seismic evidence indicated uplift that ended prior to Pliocene time. Vernon (1951) believed the feature to be a pre-Miocene structure. Riggs (1979 a, b) considered the Sanford High the "other positive element of extreme importance" in relation to phosphorite deposition.

Extending from the Sanford High are the St. Johns Platform to the north and the Brevard Platform to the south (Figure 4). Both are low, broad ridges or platforms expressed on the erosional surface of the Ocala Group. The St. Johns Platform plunges gently to the north-northwest towards the Jacksonville Basin. The Brevard Platform plunges gently to the south-southeast and southeast. The names of both features were introduced by Riggs (1979 a, b).

The Jacksonville Basin, located in northwest Florida, is the most prominent low in the northern half of the peninsula. In the deepest part of the basin the Hawthorn Group sediments exceed 500 feet (150 meters) in thickness. The name Jacksonville Basin was first used by Goodell and Yon (1960). Leve (1965) believed the basin was at least in part fault controlled.

Previously, many authors included the Jacksonville Basin in the Southeast Georgia Embayment. As more data became available it became apparent that an eastward dipping positive feature, informally named the Nassau Nose (Scott, 1983), separated the Jacksonville Basin from the rest of the Southeast Georgia Embayment. The Jacksonville Basin should still be considered as a subbasin of the larger embayment. The Southeast Georgia Embayment was named by Toulmin (1955) and appears to have been active from Middle Eocene through Miocene time (Herrick and Vorhis, 1963).

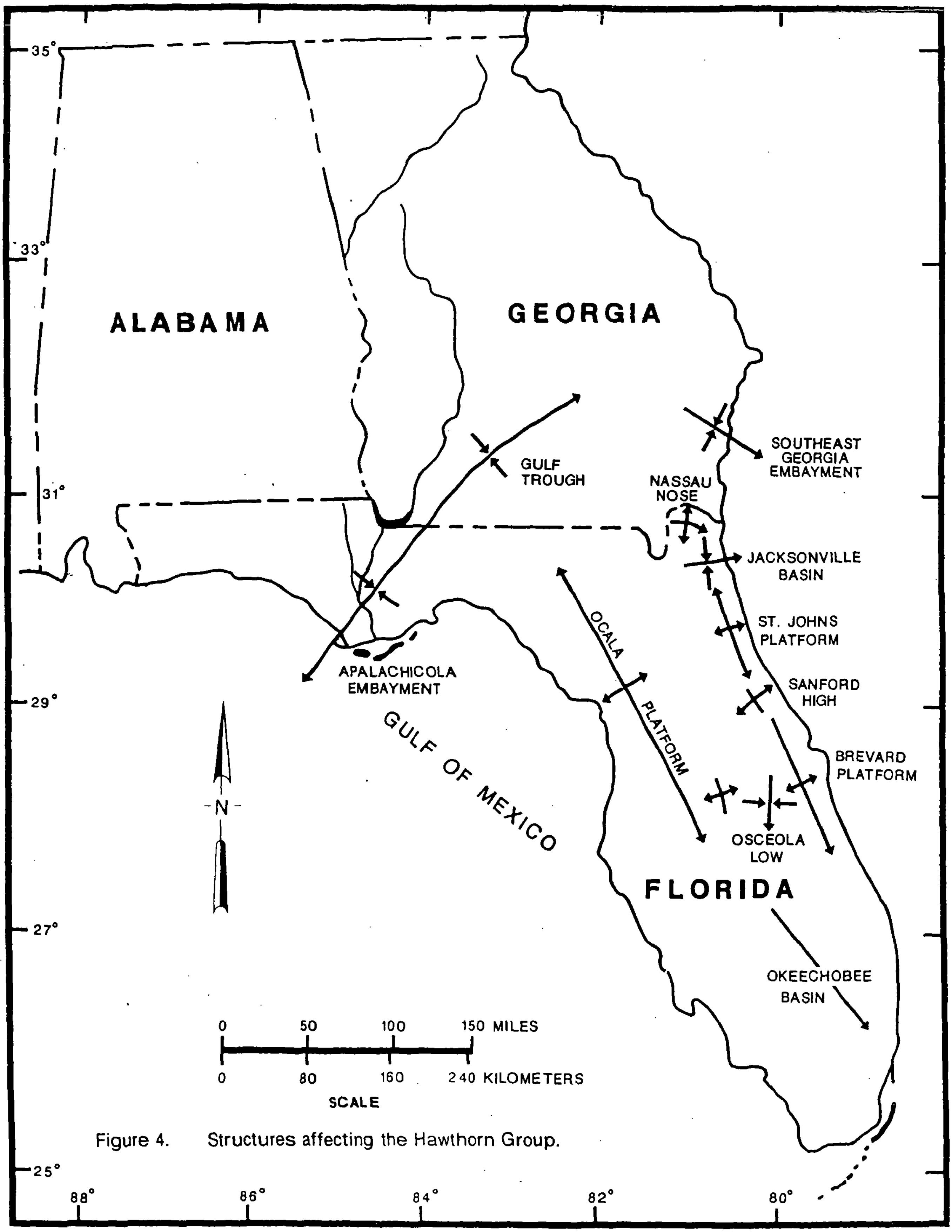


Figure 4. Structures affecting the Hawthorn Group.

The Gulf Trough or Channel extends from the Southeast Georgia Embayment to the Apalachicola Embayment (Figure 4). It is the Miocene expression of the older Suwannee Straits. The Suwannee Straits effectively separated the siliciclastic facies to the north from the carbonate facies to the south during the Early Cretaceous. The Gulf Trough was nearly full of sediments by the Late Oligocene and Early Miocene time, allowing increasing amounts of siliciclastic material to invade the carbonate environments of the peninsular area. Schmidt (1984) provided an excellent discussion of the history of both the Suwannee Strait and the Apalachicola Embayment.

In central peninsular Florida between the southern end of the Ocala Platform and the Brevard Platform are two important features in relation to the Hawthorn Group. The Osceola Low and the Kissimmee Faulted Flexture (Figure 4) were both named by Vernon (1951). Vernon considered the Kissimmee Faulted Flexure to be "a fault-bounded, tilted, and rotated block" with "many small folds, faults, and structural irregularities." His "flexure" is actually a high on the Avon Park surface with the Ocala and Hawthorn Groups absent over part of it due to erosion.

The Osceola Low, as described by Vernon (1951), is a fault-bounded low with as much as 350 feet (106 meters) of Miocene sediments. This author has investigated the Osceola Low using cores, well cuttings and geophysical data (Florida Geological Survey, unpublished data). The data does not indicate the presence of a discrete fault. They do suggest a possible flexure or perhaps a zone of displacement with "up" on the east, "down" on the west. This zone also appears to be the site of increased frequency of karst features developed in the Ocala Group limestone. Scott and Hajishafie (1980) indicated that the Osceola Low trends from north-south to northeast-southwest.

The Okeechobee Basin as named by Riggs (1979 a, 1979 b) encompasses most of southern Florida (Figure 4). It is an area where the strata generally gently dips to the south and southeast. Pressler (1947) referred to this area as the South Florida Embayment stating that its synclinal axis plunged towards the Gulf (to the southwest and/or west). Since this differs significantly from the Okeechobee Basin, the term Okeechobee Basin is preferred and utilized in this study. Within the basin there have been postulated episodes of faulting (Sproul et al., 1972) and folding (Missimer and Gardner, 1976).

INTRODUCTION TO LITHOSTRATIGRAPHY

The Hawthorn Group has long been considered a very complex unit. Puri and Vernon (1964) declared the Hawthorn "the most misunderstood formational unit in the southeastern United States." They further considered it as "a dumping ground for alluvial, terrestrial, marine, deltaic, and pro-deltaic beds of diverse lithologic units... ." Pirkle (1956b) found the dominant sediments to be quite variable stating, "The proportions of these materials vary from bed to bed and, in cases, even within a few feet both horizontally and vertically in individual strata."

HAWTHORN FORMATION TO GROUP STATUS: JUSTIFICATION, RECOGNITION AND SUBDIVISION IN FLORIDA

Formational status has been applied to the Hawthorn since Dall and Harris named the "Hawthorne beds" in 1892. As is evident from the Previous Investigations section, there has been much confusion concerning this unit. The complex nature of the Hawthorn caused many authors to suggest that the Hawthorn Formation should be raised to group status although none formally did so (Pirkle, 1956b; Espenshade and Spencer, 1963; Brooks, 1966, 1967; Riggs, 1967). The Hawthorn was referred to as a group in Georgia for several years on an informal basis until Huddlestun (in press) formalized the status change in the southeastern United States, recognizing its component formations in Georgia. The recognition of formations within the Hawthorn Group in Florida is warranted due to the lithologic complexity of the sediments previously referred to as the Hawthorn Formation. The extension of several Georgia units into Florida and the creation of new Florida units is based on the expectation that Huddlestun will validly publish the status change from formation to group. If he fails to do so, this text will be amended to validate the necessary changes in the proper manner according to the North American Code

of Stratigraphic Nomenclature (1983).

An original type locality for the Hawthorn Group was not defined within the limits of our present stratigraphic code. However, it appears that Dall and Harris' (1892) intention was to use the old Simmons pits near Hawthorne in Alachua County as the type locality (holostratotype). The other sections referred to by Dall and Harris (1892) at Devil's Millhopper, Newnansville well, and White Springs were reference sections. The old Simmons pit is no longer accessible indicating the need for a new type locality (neostratotype). The Hawthorne #1 core W-11486, located in Alachua County drilled in the vicinity of the old Simmons pit should fill this gap. As such the Hawthorne #1 core is designated as a neostratotype or replacement (accessible) type section for the Hawthorn Group.

Although many authors have agreed that the Hawthorn deserves group status, questions remain. What should be included in the group and what should be the stratigraphic status of the units (i.e., formations with or without members)? The approach used in this study has been to identify lithostratigraphic units within the study area, determine their areal extent and thickness and, based on these findings, assign a formational status where appropriate. Having done that, as detailed subsequently in this report, the Hawthorn Formation of Florida is herein raised to group status. Its formations are described and type sections or cores are designated in accordance with the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature (NACSN), 1983). Utilizing the group concept will enable geologists to better understand the framework of the Miocene sediments in Florida and much of the southeastern Coastal Plain.

The sediments placed in the Hawthorn Group are related by the occurrence of phosphate, a palygorskite-sepiolite-smectite clay mineral suite and the mixed carbonate-siliciclastic nature of the entire sequence. Color, particularly in the siliciclastic portions, is often distinctive in the sediments of this group. In some regions and in specific intervals, lithologic heterogeneity provides a diagnostic trait of the Hawthorn Group.

The component formations of the Hawthorn Group vary from region to region within the State. The variation is the result of the depositional and environmental controls exerted on the Hawthorn sediments by features such as the Ocala Platform, the Sanford High, the St. Johns Platform, and the Brevard Platform. The variation in component formations of a group is discussed in and accepted by the North American Commission on Stratigraphic Nomenclature (Article 28b, North American Stratigraphic Code, 1983).

The name Hawthorn is retained for the group since the group represents a series of units that had been recognized as the Hawthorn Formation. Only a few changes (additions) are proposed in this report that alter the overall boundaries of the former Hawthorn Formation. Due to its wide use and acceptance, dropping the term Hawthorn and providing a new group name would cause unnecessary confusion.

Once the lithostratigraphic units were determined, names were selected for the respective sections. These are listed in Table 1 along with reference to the original author. When possible, names currently in use, or proposed in a bordering State (Georgia), were used in Florida. Examples of these are the Marks Head, Coosawhatchie and Statenville Formations currently recommended for use in Georgia (Huddlestun, in press). Where a sediment package exhibited significant variation in Florida from the equivalent unit in Georgia, a new name is proposed (i.e., the Penney Farms Formation).

In the eastern panhandle the name Torreya Formation is used since it is already in the literature (Banks and Hunter, 1973; Huddlestun and Hunter, 1982; Hunter and Huddlestun, 1982; Huddlestun, in press) and there is insufficient evidence to suggest any changes. Future research, however, may suggest further changes.

The names of the formational units of the Hawthorn Group in southern Florida were selected based on historical perspective and current usage. The name Arcadia Formation is reintroduced for the Hawthorn carbonate unit. The use of Arcadia is similar to the use suggested by Riggs (1967). Two members are named in the Arcadia, the Tampa Member and the Nocatee Member. These members do not comprise the entire Arcadia but only represent the lower Arcadia where they are identifiable.

The Tampa Member represents a reduction in status for the Tampa from formation to member. Since this reduction represents only a minor alteration of the Tampa definition and since the name Tampa is

widely used and recognized, a new name is not suggested for this member. The most prominent reasons for reducing the Tampa to member status is the limited area of recognition and its lithologic affinities with the rest of the Arcadia Formation of the Hawthorn Group.

A new name, the Peace River Formation, is proposed for the upper Hawthorn siliciclastic section, including the Bone Valley Formation of former usage. The Bone Valley Formation is reduced to member status and the name is retained for the same reasons discussed for the Tampa Member. There has been some discussion and disagreement concerning including the entire Bone Valley in the Hawthorn Group due to the presence of a major, Late Miocene unconformity. This unconformity separates the upper gravel bed of the Bone Valley from the remainder of the unit and often is recognizable only on a biostratigraphic basis using vertebrate faunas. The unconformity is generally not recognized on a lithostratigraphic basis. The North American Stratigraphic Code (NACSN, 1983) recognizes this problem. Article 23d states "...a sequence of similar rocks may include an obscure unconformity so that separation into two units may be desirable but impractical. If no lithic distinction adequate to define a widely recognizable boundary can be made, only one unit should be recognized, even though it may include rock that accumulated in different epochs, periods or eras (NACSN, 1983)."

The formations of the Hawthorn Group are similar yet different in northern and southern Florida and in the eastern panhandle. Also, within southern Florida, the group varies from east to west. As a result the discussion of the Hawthorn will be presented separately for northern and southern Florida and the eastern Florida panhandle (Figure 1).

PRESENT OCCURRENCE

The Hawthorn Group underlies much of peninsular Florida (Figures 5 and 6). It is absent from most of the Ocala Platform and Sanford High due to erosion. Outliers of Hawthorn sediments and residuum occur scattered along the platform in lows and in some karst features. The Hawthorn Group sediments are also absent from part of Vernon's (1951) Kissimmee Faulted Flexure in Osceola County presumably due to erosion.

The Hawthorn Group dips gently away from the Ocala Platform and Sanford High at generally less than 6 feet per mile (1.1 meters per kilometer) (Figure 5). In north Florida, the Hawthorn dips generally to the east and northeast towards the Jacksonville Basin and the east coast. Locally the dip may become greater and may reverse in some areas. This is due to postdepositional movement related to karst activity, subsidence, possible faulting, and tilting of the platform. Scott (1983) indicated this on structure maps of the Ocala Group (p. 29) and the Hawthorn Formation (p. 32).

In central and south Florida the Hawthorn Group dips gently to the south and southeast with local variations (Figure 5). Generally, further south in the state the dip is more southeasterly. The strata dip to the west and southwest along the western edge of the state from Pasco County south to Lee County.

The Hawthorn Group ranges in thickness from a feather edge along the positive features to greater than 500 feet (160 meters) in the Jacksonville Basin and greater than 700 feet (210 meters) in the Okeechobee Basin (Figures 4 and 6). The Hawthorn generally thickens to the northeast in north Florida toward the Jacksonville Basin and southward into the Okeechobee Basin (Figure 6).

NORTH FLORIDA

INTRODUCTION

The Hawthorn Group in Florida, north of Orange County and west through Hamilton County, has distinct affinities to the Hawthorn in Georgia. The sediments of the upper two-thirds of the group are very similar to those in Georgia, facilitating the use of the same terminology in both states. The basal one-third of the group changes significantly into Florida and, therefore, a new formational name is proposed.

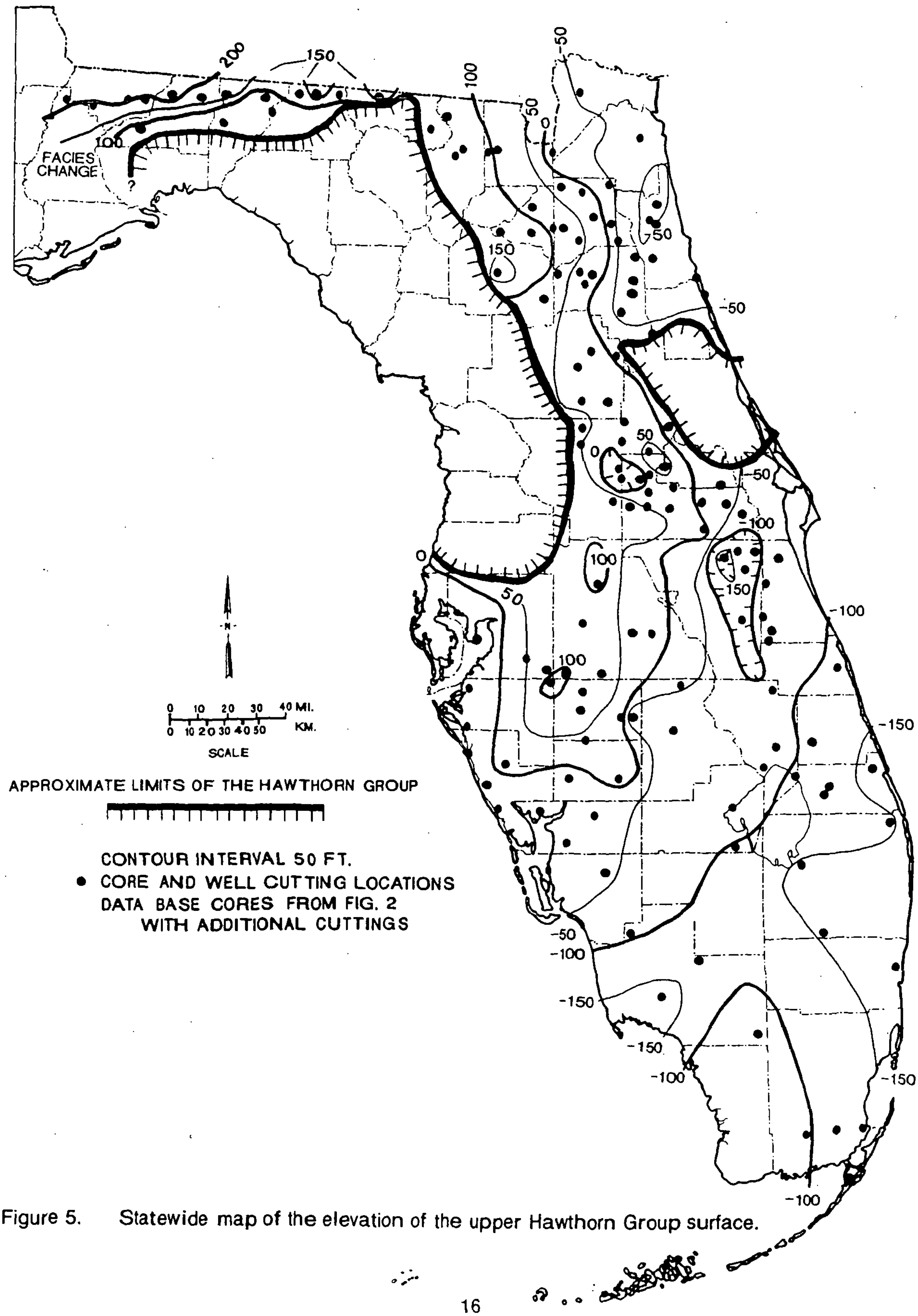


Figure 5. Statewide map of the elevation of the upper Hawthorn Group surface.

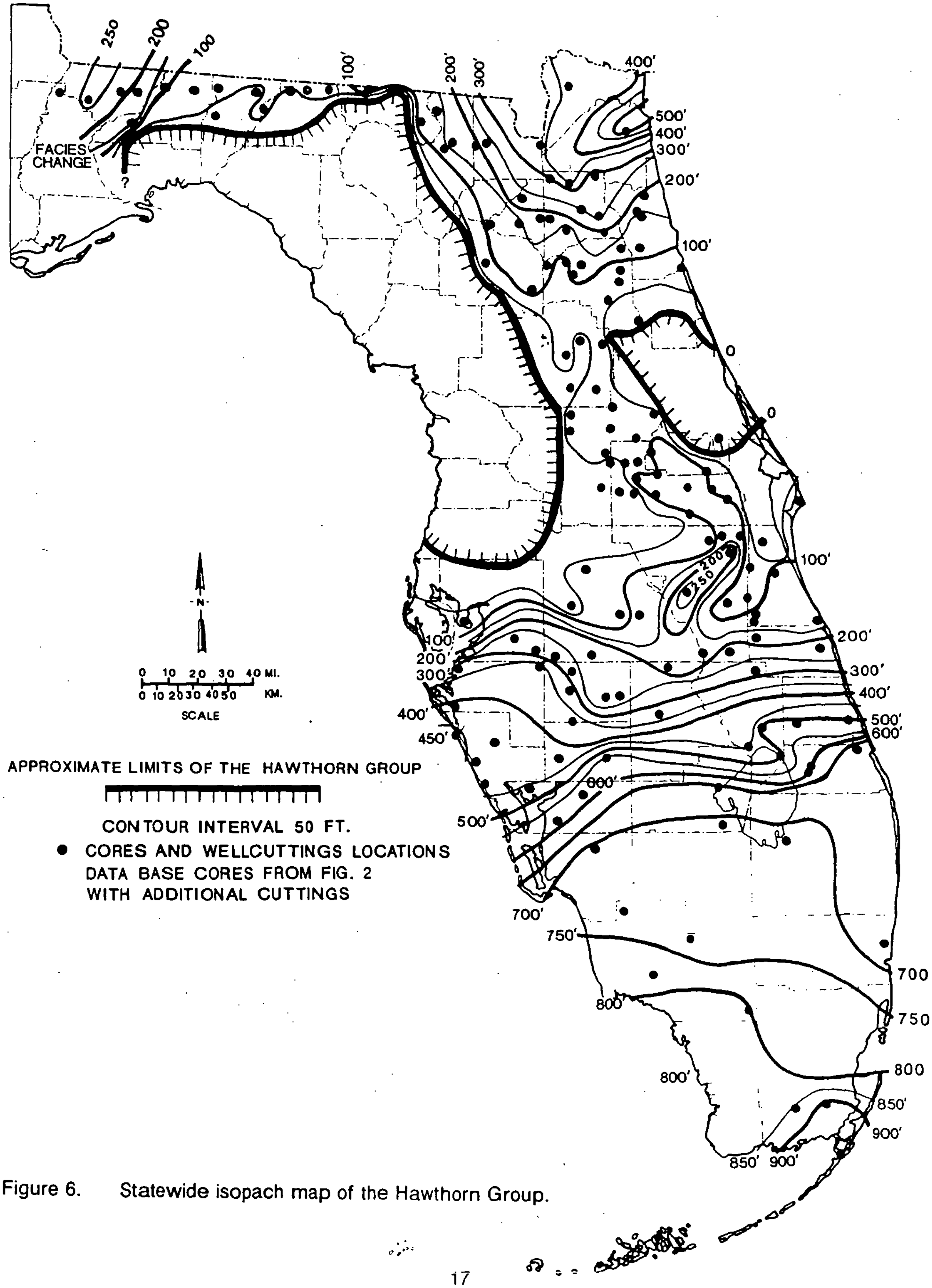


Figure 6. Statewide isopach map of the Hawthorn Group.

The Hawthorn Group in north Florida can be subdivided into four formations as indicated in Figure 7. From oldest to youngest, these are the Penney Farms Formation, the Marks Head Formation, the Coosawhatchie Formation, and the Statenville Formation. The Penney Farms Formation can be divided into two informal members referred to simply as upper and lower members. The Coosawhatchie Formation also has upper and lower informal members and the Charlton Member (Huddlestun, in press) (Figure 7).

The formational breakdown of the Hawthorn Group in north Florida is recognizable in cores. However, due to the highly variable nature of the north Florida Hawthorn sediments, the individual units are very difficult to identify in well cuttings. Therefore it is recommended that when using well cuttings in this area these sediments simply be referred to as Hawthorn Group undifferentiated.

The sediments of the Hawthorn Group are significantly different west of the crest of the Ocala Platform (west of Hamilton County). These units will be discussed separately from those east of the crest in north Florida.

The Hawthorn Group in north Florida shows significant variation when traced into central Florida. In the area between the Sanford High and the Ocala Platform, the Hawthorn is thinned both depositionally and erosionally (Figure 6). Within this zone the upper part of the group changes character, such that it is difficult to correlate with the formations to the north. The basal unit of the group carries through this area, and is apparent in east central Florida where it grades into the lower part of the Arcadia Formation of southern Florida.

Throughout most of the north Florida region the Hawthorn Group unconformably overlies the Upper Eocene Ocala Group (Figure 8). The Crystal River Formation of the Ocala Group underlies the Hawthorn in most of the area where the Ocala Group occurs. However, in areas peripheral to the Sanford High and in portions of the transition zone, the Hawthorn overlies the lower Ocala Group (Williston Formation). The author has not encountered any instances of the Hawthorn overlying the Avon Park Formation when the Ocala Group is absent since the Hawthorn Group is also absent in these cases (Sanford High, for instance). The sediments of the subjacent Ocala Group are typically cream to white, foraminiferal grainstone to wackestone, containing no quartz sand. The limestones are often recrystallized just below the contact with the Hawthorn Group. This contrast of lithologies with the basal Hawthorn Group is generally dramatic, resulting in little confusion in identifying the contact.

The Suwannee Limestone of Oligocene age unconformably underlies the Hawthorn Group on the northeastern-most portion of the Ocala Platform in Hamilton and Columbia Counties. Typically, the Suwannee is a granular, microfossiliferous, cream, white, to very pale orange grainstone to wackestone. It is sometimes recrystallized below the contact with the Hawthorn and rarely may be a dolostone. The lithologic differences between the basal Hawthorn Group sediments and the Suwannee Limestone are quite distinctive; confusion concerning the contact is unlikely.

The St. Marks Formation of Early Miocene age underlies the Hawthorn in an extremely limited area in the western half of Hamilton County. The St. Marks occurs sporadically and generally is less than 30 feet (9 meters) thick (Colton, 1978). Lithologically, the St. Marks is a quartz sandy, silty, sometimes clayey limestone (wackestone to mudstone). Occasionally, it may be dolomitized. The lithology of this unit is similar to the basal Hawthorn sediments except for the lack of phosphate grains in the St. Marks. The St. Marks lithology may occur within the basal Hawthorn carbonates, creating possible confusion concerning the contact. Although the contact is unconformable, it is often not apparent. As a result, the top of the St. Marks is placed below the last occurence of phosphatic sediments. This datum is traceable from western Hamilton County westward into the eastern panhandle in Madison, Jefferson, and Leon Counties.

PENNEY FARMS FORMATION

Definition and Type Locality

The Penney Farms Formation is a new lithostratigraphic name proposed here for the predominantly subsurface basal unit of the Hawthorn Group in north and central Florida. It is named after the town of

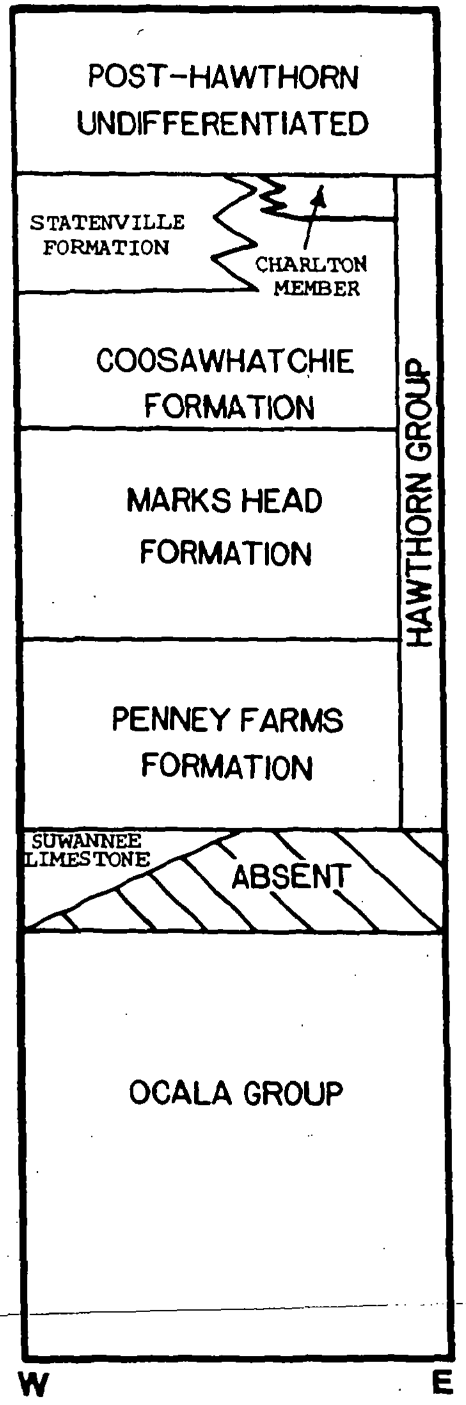


Figure 7. Lithostratigraphic units of the Hawthorn Group in north Florida.

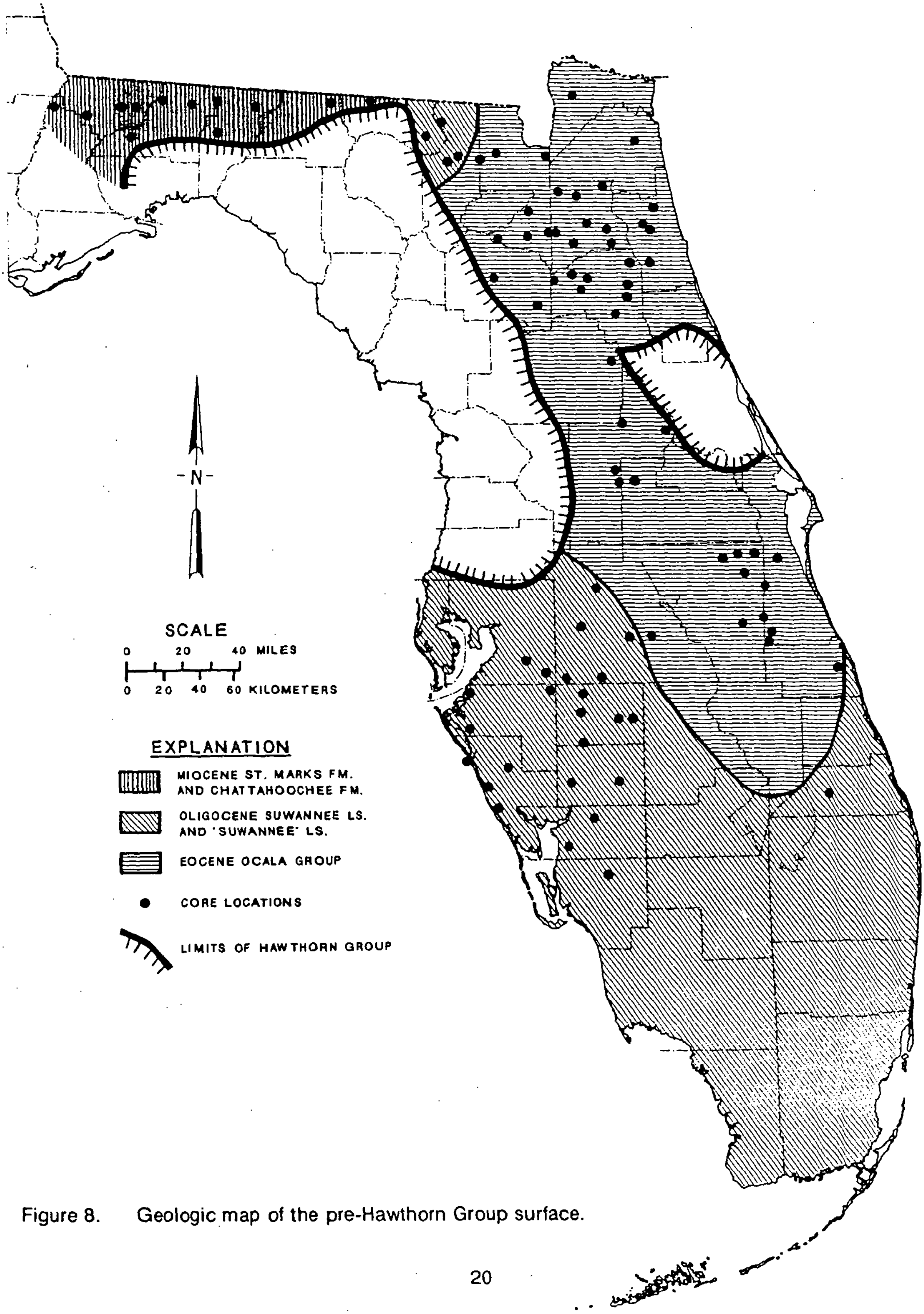


Figure 8. Geologic map of the pre-Hawthorn Group surface.

Penney Farms in central Clay County, Florida. The type core, W-13769 Harris #1, is located near Penney Farms (SW¼, SE¼, Section 7, Township 6S, Range 25E) with a surface elevation of 97 feet (30 meters). The type core was drilled by the Florida Geological Survey in December 1977 and is permanently stored in the Survey's core library. The type Penney Farms Formation occurs between -118 feet MSL (-36 meters) and -205 feet MSL (-63 meters) (Figure 9).

Lithology

The Penney Farms Formation consists of two informal, unnamed members which are distinguished from each other based on the abundance of carbonate beds. Figure 9 graphically shows the variable nature of this formation and its general two member framework. Each member consists of lithologies similar to the other but the proportions of the lithologies are dissimilar. In the lower member, carbonates predominate with sands and clays interbedded in varying proportions. The upper member is a predominantly siliciclastic unit with interbedded carbonate beds. The interbedded sands and clays of the lower member generally increase in abundance upward in the section causing the contact with the upper member to be gradational in nature. The top of the lower member is placed where carbonate beds become dominant over the siliciclastic beds. The North American Code of Stratigraphic Nomenclature (NACSN, 1983) (Article 23) allows for this arbitrary placement of a boundary in a gradational sequence. Occasionally, the siliciclastic beds are abundant enough in the lower member to obscure the contact altogether thus the separation of the informal members within the Penney Farms Formation is not always possible.

The carbonates are variably quartz sandy, phosphatic, clayey dolostones. Sand content is variable to the point that the sediment may become a dolomitic sand. Phosphate grains may be present in amounts greater than 25 percent with an average of approximately 5 to 10 percent. Clay percentages are generally minor (below 5 percent) but often increase in the dolostones of the upper member. The dolostones are medium gray (N5) to pale yellowish brown (10 YR 6/2). They are generally moderately to well indurated and finely to coarsely crystalline in the lower member. The dolostones of the upper member are generally less indurated. Thicker, more massive beds predominate in the lower unit while thinner beds are most common in the upper section. Mollusk molds are common in the dolostones, particularly in the more coarsely crystalline type.

Zones of intraclasts are common in the hard, finer grained dolostones of the lower part of the Penney Farms. The intraclasts are composed of dolomite that is essentially the same as the enclosing matrix. The intraclasts are recognizable due to a rim of phosphate replacement along the edges of the clasts (Figure 10). Edges of the clasts vary from angular to subrounded indicating very little to no transport of the fragments. They also may be bored, indicating at least a semi-lithified state prior to being redeposited.

Limestone, in the basal portion of the Penney Farms Formation, occurs sporadically. When it does occur, it is generally dolomitic, quartz sandy and phosphatic.

The quartz sands are fine to coarse grained, moderately to poorly sorted, variably phosphatic, dolomitic, silty and clayey. The phosphate grain content varies considerably, sometimes to the point of being classified as phosphorite sand (50 percent or greater phosphate grains). In general, however, the phosphate grain content averages between 5 and 10 percent. The sands are typically olive gray (5 Y 3/2) or grayish olive (10 Y 4/2) to medium light gray (N 6). Clay content varies considerably in the sands.

Clay beds in the Penney Farms Formation are typically quartz sandy, phosphatic, silty and dolomitic. The proportions of the accessory minerals vary from nearly zero to more than 50 percent. Nearly pure clay beds are uncommon. Dolomite is very common in the clays, often being the most abundant accessory mineral. Olive gray (5 Y 3/2) and grayish olive green (5 GY 3/2) colors generally predominate, but colors may range into the lighter shades. Smectite typically dominates the clay mineralogy of this unit with palygorskite, illite and sepiolite also present. X-ray analyses by Hettrick and Friddell (1984) indicate that palygorskite may become predominant over smectite in some samples. Reik (1982) indicated that palygorskite dominates in the lower part of the Penney Farms while smectite dominates in the upper por-

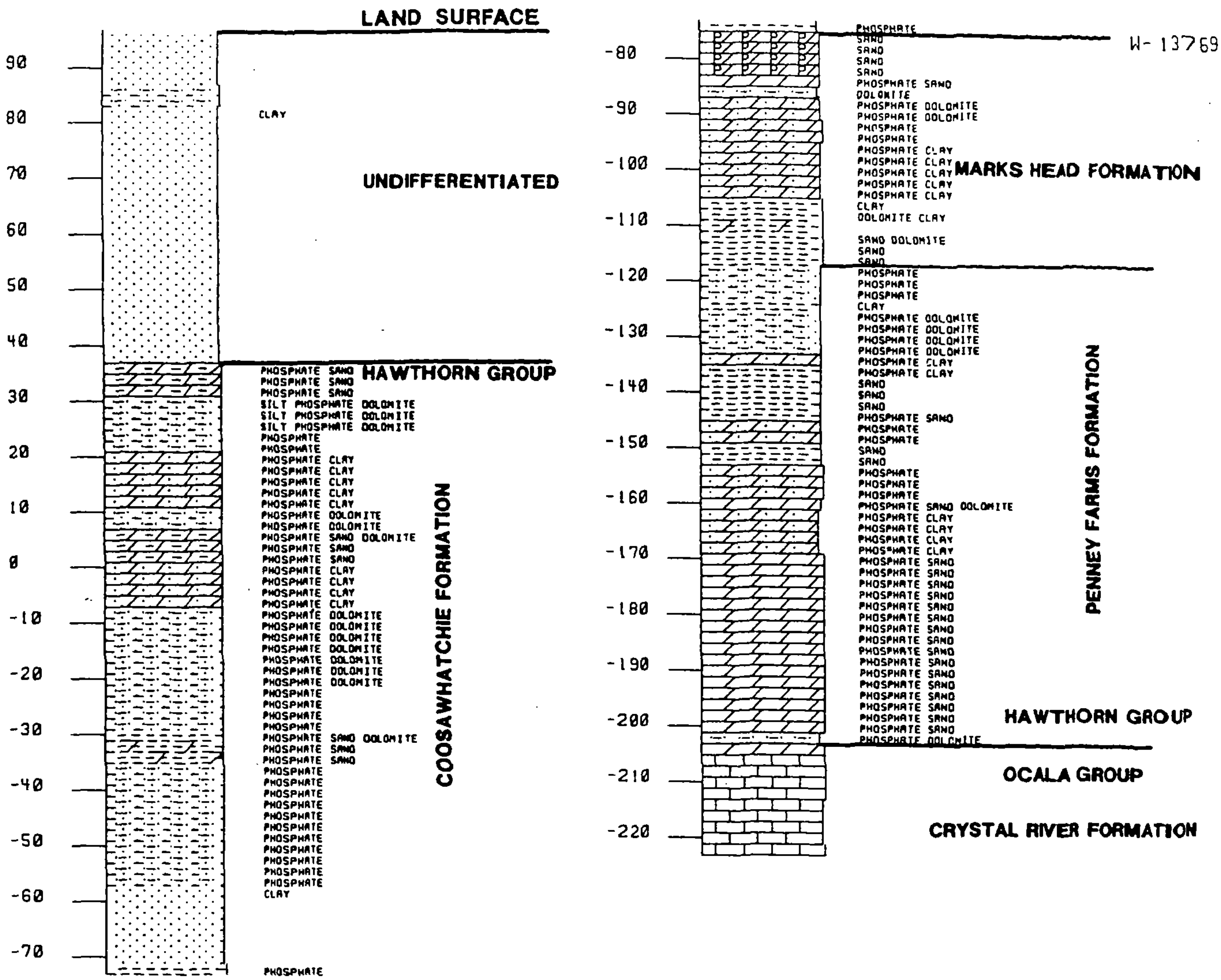


Figure 9. Type section of the Penney Farms Formation, Harris #1, W-13769, Clay County (Lithologic legend Appendix A).

Figure 10. Intraclasts with phosphatic rims from Penney Farms Formation, St. Johns County, W-13844.

tion in Clay County. Other minor mineralogic constituents include mica, K-feldspar and opal ct. Clinoptilolite has been identified in a few samples (Huddlestun, in press).

When abundant silt-sized, unconsolidated dolomite occurs, difficulty arises in determining whether the actual rock type is a very dolomitic clay or a very clayey dolostone. Insoluble residue analysis is the only accurate method of determining the clay and dolostone contents. Rough analysis indicates that, in general, the lighter the color of the sediment, the higher the dolomite content. This method was employed for determining the sediment type in these situations.

The siliciclastic beds of the Penney Farms Formation are lithologically very similar to those in the Parachucla Formation in southeastern Georgia (Huddlestun, in press). As the Penney Farms Formation begins to lose its carbonate units northward and northwestward into Georgia, the characteristic lithologies are no longer apparent and the formation can no longer be identified as the Penney Farms. These sediments in Georgia are included in the Parachucla Formation (Huddlestun, in press).

Southward into central Florida, the Penney Farms contains more carbonate than in the type area. Between the Sanford High and the Ocala Platform in portions of Lake and western Orange Counties, the percentage of siliciclastic beds decreases to the point that the separation of upper and lower members becomes unfeasible. The carbonates in this area contain coarser sand and a noticeably coarser phosphate grain fraction.

Further to the east, in Orange County, and southward into eastern Osceola and Brevard Counties, the basal Hawthorn Group consists predominantly of dolostone. This basal unit is tentatively placed in the Arcadia Formation until further investigations can be conducted.

Subjacent and Suprajacent Units

The Penney Farms Formation unconformably overlies limestones of the Eocene Ocala Group or the Oligocene Suwannee Limestone. Figure 8 indicates the areas in which each occurs. The unconformity is very apparent due to the drastically different lithologies. Previous discussion of the base of the Hawthorn Group in north Florida descibes the lithologic differences in greater detail.

The Marks Head Formation unconformably overlies the Penney Farms Formation throughout north Florida except in those areas where it has been removed by erosion. In areas where the Marks Head has been eroded, the Penney Farms is overlain by sands and clays classified as undifferentiated post-Hawthorn deposits.

The top of the Penney Farms is placed at the break between the lighter colored sediments of the Marks Head and the darker colored sands and clays of the upper part of the Penney Farms. Occasionally, a rubble zone marks the break between the Marks Head and the Penney Farms Formations. When it occurs, the rubble consists of clasts of phosphatized carbonate.

The relationship of the Penney Farms Formation and to the underlying and overlying sediments is illustrated in Figures 11 through 16.

Thickness and Areal Extent

The Penney Farms Formation of the Hawthorn Group occurs primarily as a subsurface unit. The top of the Penney Farms Formation ranges in cores from -333 feet MSL (-101 meters) in Carter #1, W-14619, Duval County to +80 feet MSL (24.3 meters) in Devils Millhopper #1, W-14641, Alachua County (Figure 17). Limited data from one outcrop in Marion County (Martin-Anthony roadcut, NE¼, NE¼, NE¼, Sec. 12, Township 14S, Range 21E) indicates the sediments assigned to the Penney Farms occur at +140 to +150 feet MSL (43 to 46 meters). This is the only recognized occurrence of the basal Hawthorn Group at elevations this high.

The Penney Farms Formation dips in a general northeasterly direction from the flanks of the Ocala Platform toward the Jacksonville Basin with an average dip of 4 feet per mile (0.8 meters per kilometer). The direction of dip of the Penney Farms trends toward the north into the Jacksonville Basin from the St. Johns Platform (Figure 17). Locally, both the direction and angle of dip may vary.

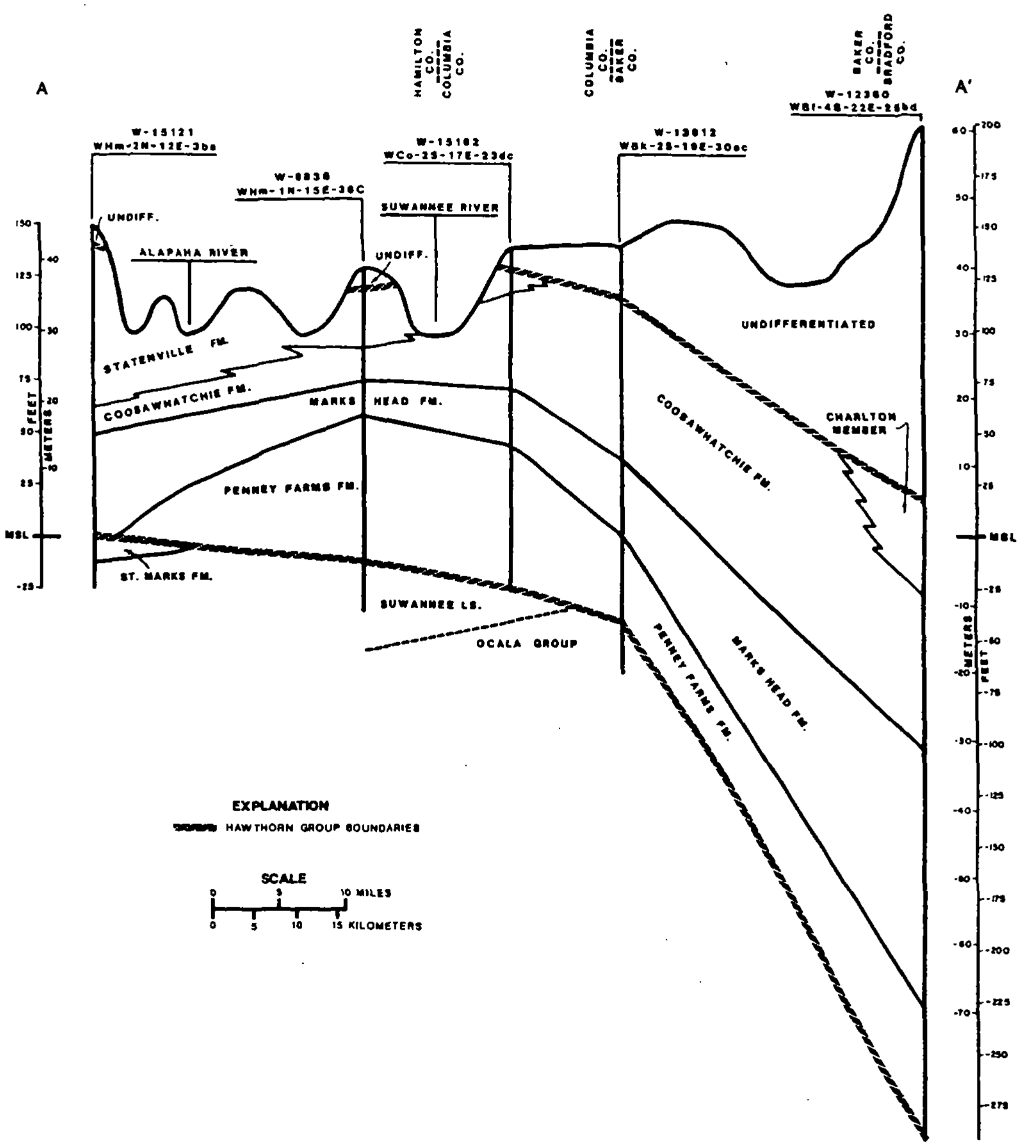


Figure 11. Cross section A-A' (see figure 3 for location) (See Scott (1983) for discussion of faults).

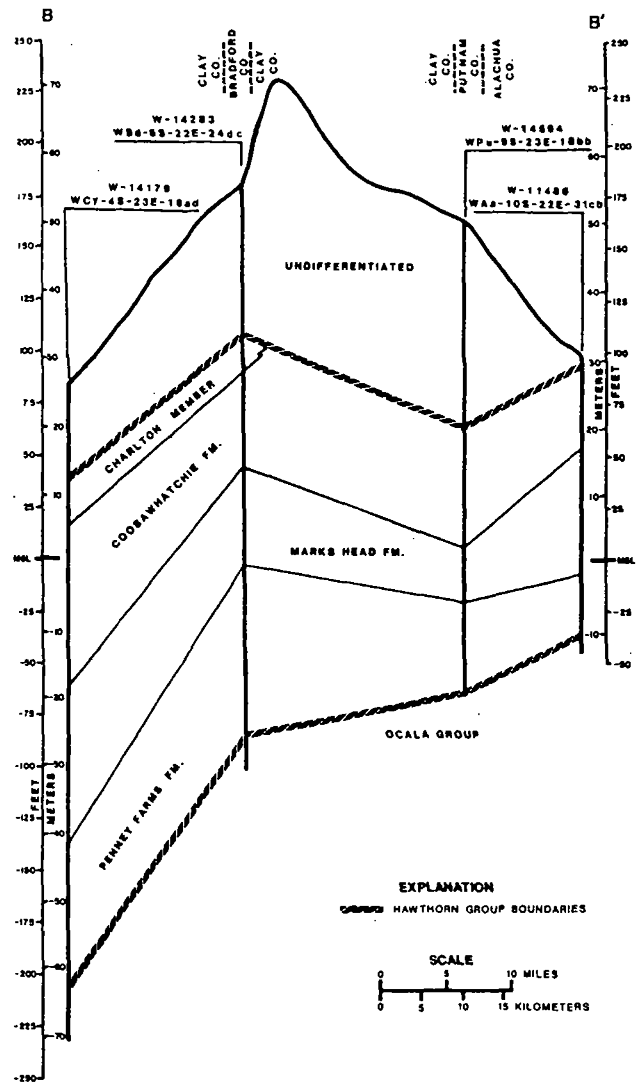


Figure 12. Cross section B-B' (see figure 3 for location) (See Scott (1983) for discussion of faults).

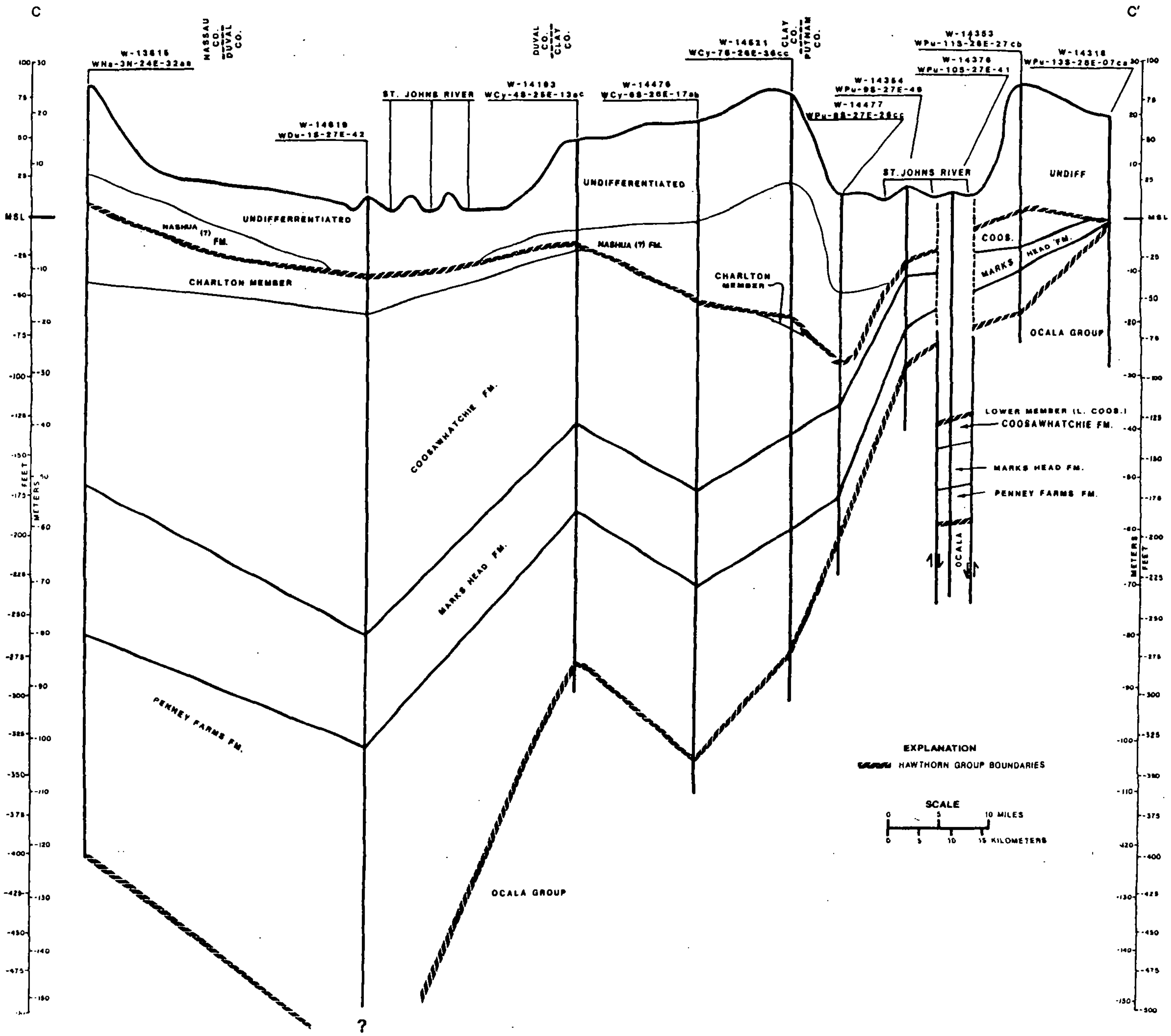


Figure 13. Cross section C-C' (see figure 3 for location) (See Scott (1983) for discussion of faults).

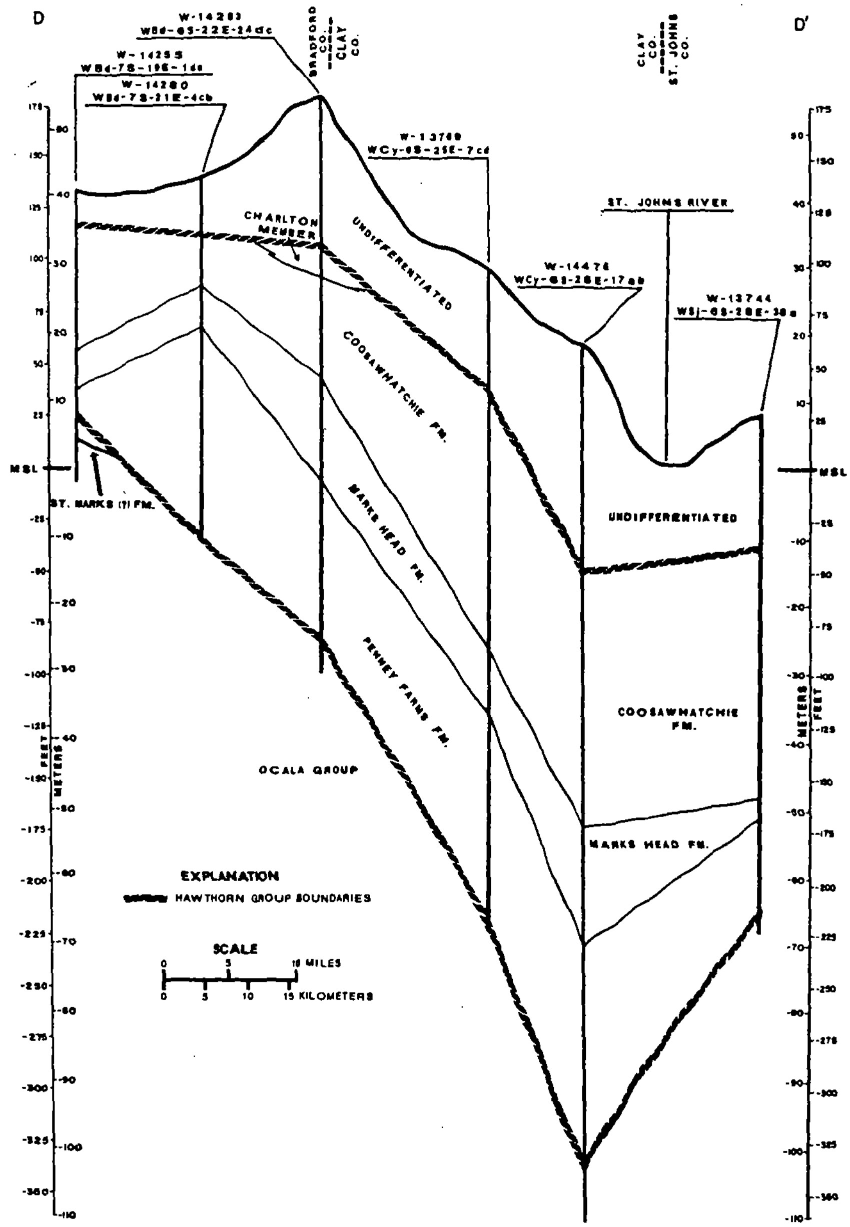


Figure 14. Cross section D-D' (see figure 3 for location) (See Scott (1983) for discussion of faults).

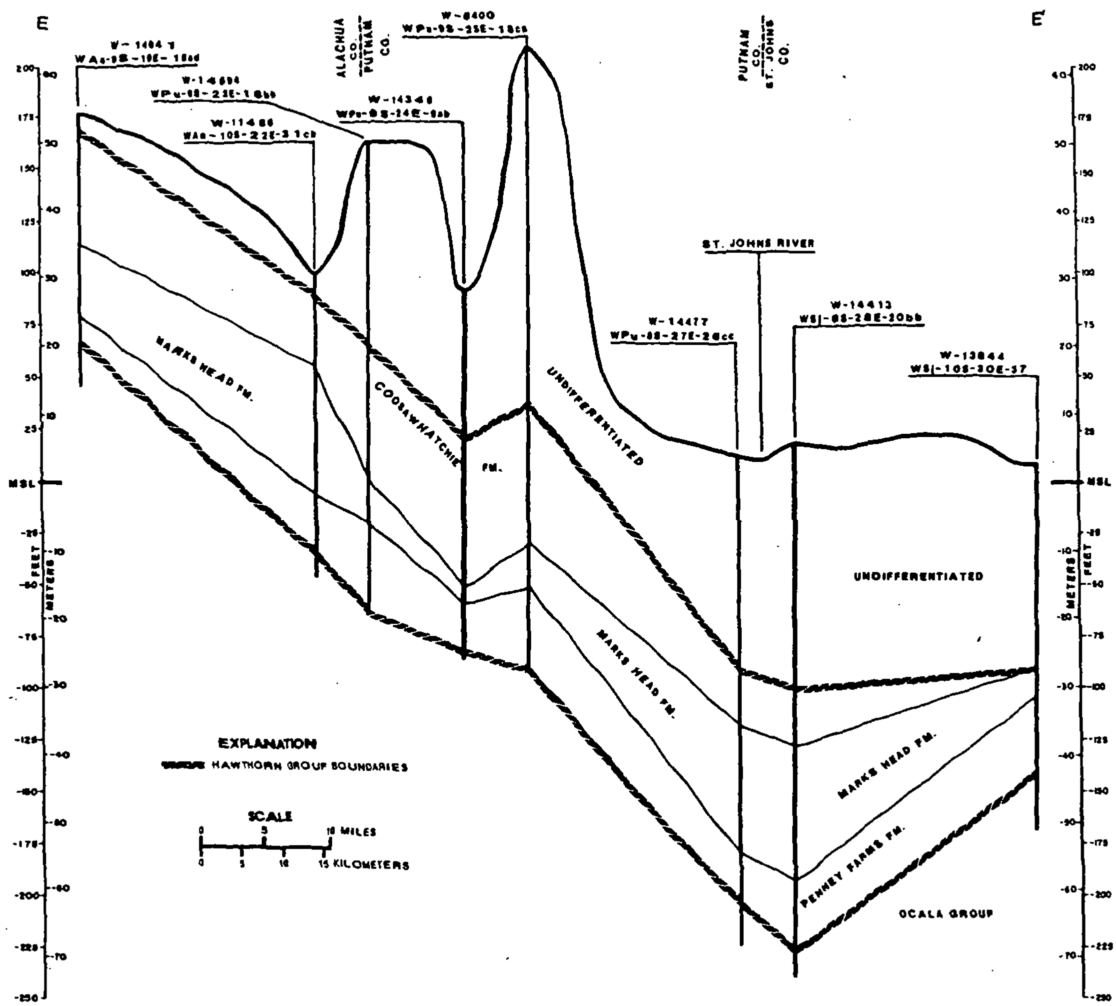


Figure 15. Cross section E-E' (see figure 3 for location) (See Scott (1983) for discussion of faults).

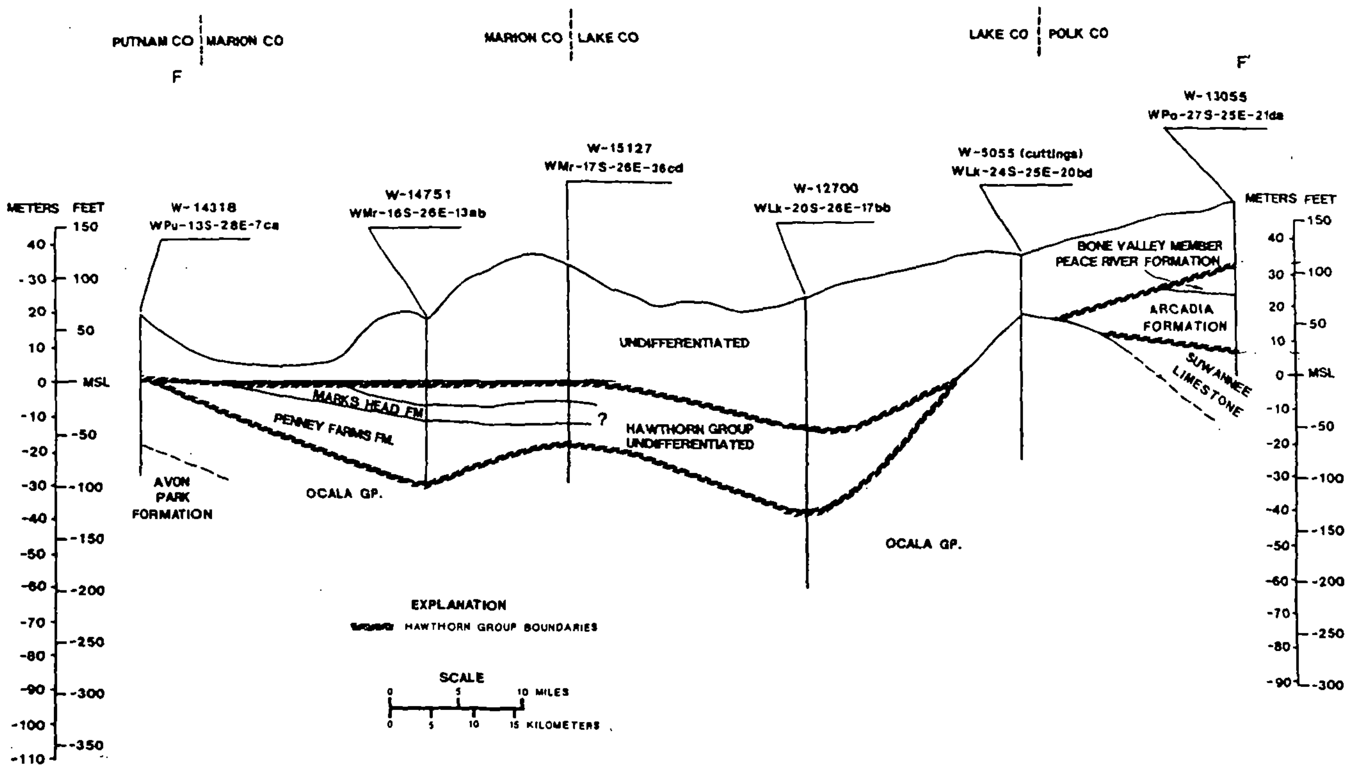


Figure 16. Cross section F-F' (see figure 3 for location) (See Scott (1983) for discussion of faults).

The Penney Farms Formation varies in thickness from being absent on the crests of the Ocala Platform and Sanford High to more than 155 feet (47 meters) in Carter #1, W-14619, Duval County in the Jacksonville Basin (Figure 18). The total thickness of this unit was not determined in this core as the core terminated in the Penney Farms Formation after penetrating 155 feet (47 meters). This author estimates that the base of the Penney Farms should occur near -575 feet (-175 meters) MSL based on nearby water wells. This suggests that approximately 230 feet (70 meters) of the unit should be present in the deepest portion of the Jacksonville Basin. The informal upper member attains its maximum observed thickness of 88 feet (27 meters) in Cassidy #1, W-13815, Nassau County. Seventy-five feet (23 meters) of the lower informal member were penetrated in W-14619. This author estimates that approximately 150 feet (46 meters) of this member should be present based on previously discussed criteria.

The Penney Farms Formation of the Hawthorn Group occurs throughout much of north and central Florida. It is absent from the crest of the Ocala Platform and the Sanford High due to erosion and nondeposition. The Penney Farms Formation thins on the St. Johns Platform and is absent from the highest part of the structure, the area where the Sanford High and the St. Johns Platform merge (Figure 4).

Age and Correlation

The Hawthorn Group sediments of northern Florida have yielded very few dateable fossils or fossil assemblages. Diagenetic overprinting on the sediments has obliterated the vast majority of fossils leaving mainly molds and casts. Diatom and mollusk molds are the most frequently encountered fossil remains.

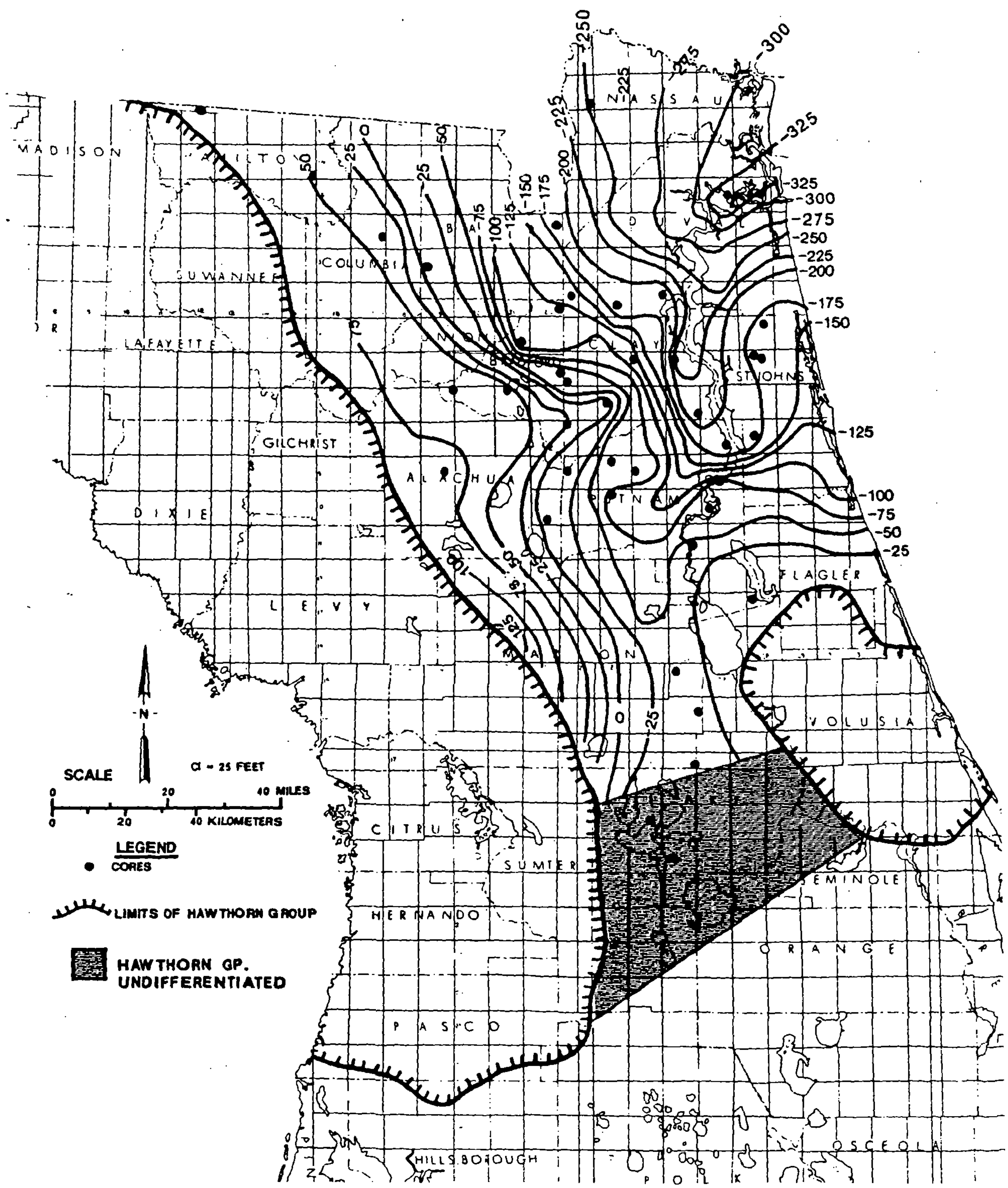


Figure 17. Top of Penney Farms Formation. Shaded area indicates undifferentiated Hawthorn Group.

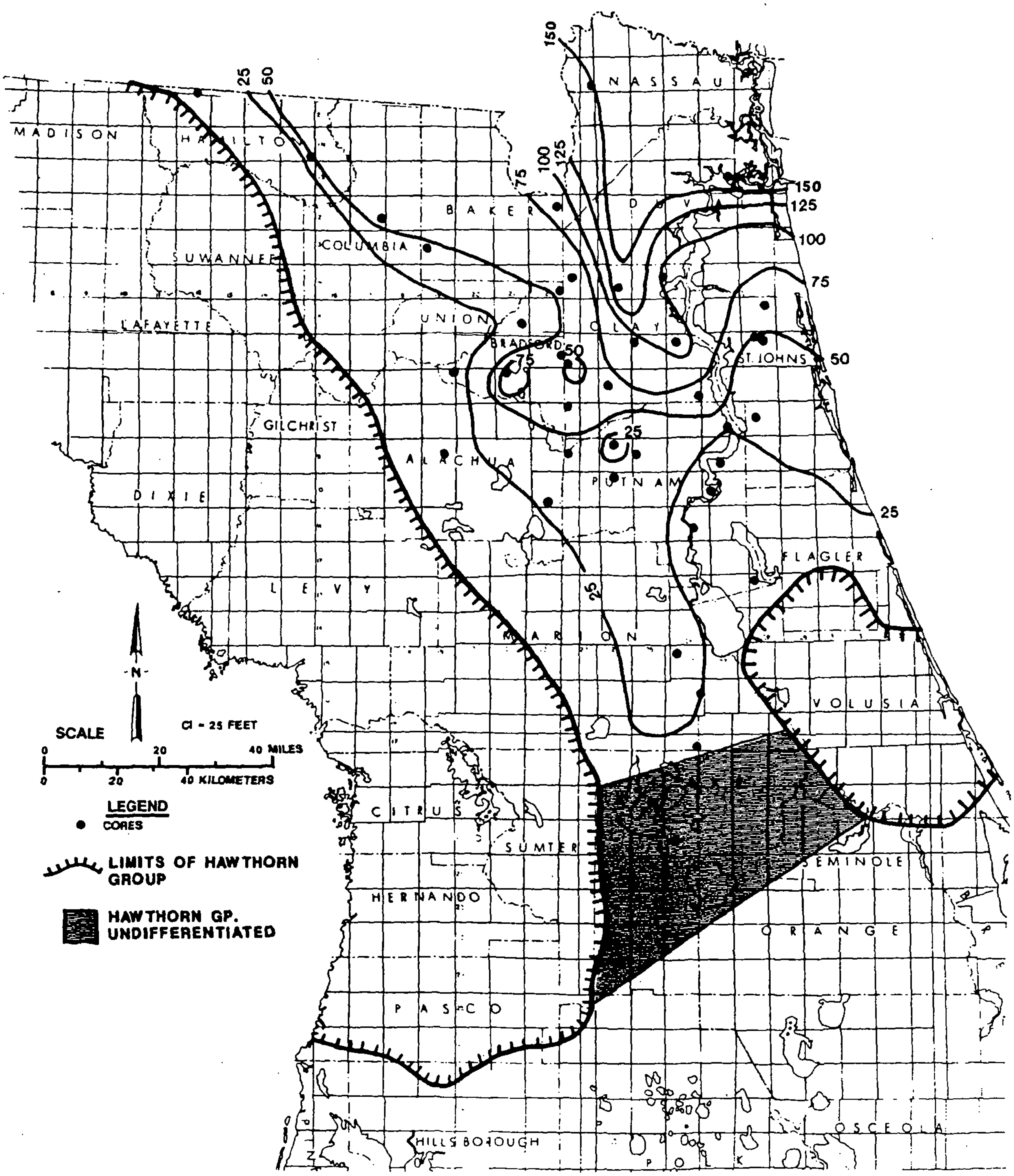


Figure 18. Isopach of Penney Farms Formation. Shaded area indicates undifferentiated Hawthorn Group.

At the present time, dateable fossils from the Penney Farms Formation have been obtained from only two sites. The first is from the Cassidy #1 core, W-13815, Nassau County in the interval from -450 to -455 feet LSD (-137 to -138.7 meters LSD). The sediment, a calcareous, quartz sandy clay, contained benthic and planktonic foraminifera, ostracods, spicules (sponge?), echinoid fragments and bryozoans. The planktonic foraminifera indicate an Aquitanian age upper Zone N.4 or lower N.5 of Blow (1969) for this interval (Huddlestun, personal communications, 1983).

The second site encompasses the Martin-Anthony roadcut in north central Marion County (NE¼, NE¼, NE¼, of Section 12, Township 14S, Range 21E). An oreodont jaw collected from the hard carbonates exposed in the roadcut was dated as Late Arikareen (equates to Early to Middle Aquitanian) (MacFadden, 1982).

The few ages obtained in north Florida correlate well with dates obtained by Huddlestun (personal communication, 1983) in the Hawthorn Group of Georgia. The age suggested for the Penney Farms Formation correlates with the age of the upper part of the Parachucla Formation in Georgia (Figure 19). Lithologically, the Penney Farms Formation grades laterally into the Parachucla Formation through a transition zone north of the Jacksonville Basin. These ages indicate that the basal portion of the Penney Farms Formation is slightly older (1-2 million years) than the base of the Pungo River Formation in the Miocene of North Carolina as indicated by Gibson (1982) and Riggs (1984).

The type Penney Farms appears to be equivalent to at least part of the Tampa Member of the Arcadia Formation (as described in this report). Based on Huddlestun's (in press) suggestion that the Parachucla Formation correlates with the Chattahoochee Formation of western Florida and southwest Georgia, the Penney Farms Formation is also equivalent to part of the Chattahoochee Formation (Figure 19). The Penney Farms appears to equate with Miller's (1978) unit E from the Osceola National Forest.

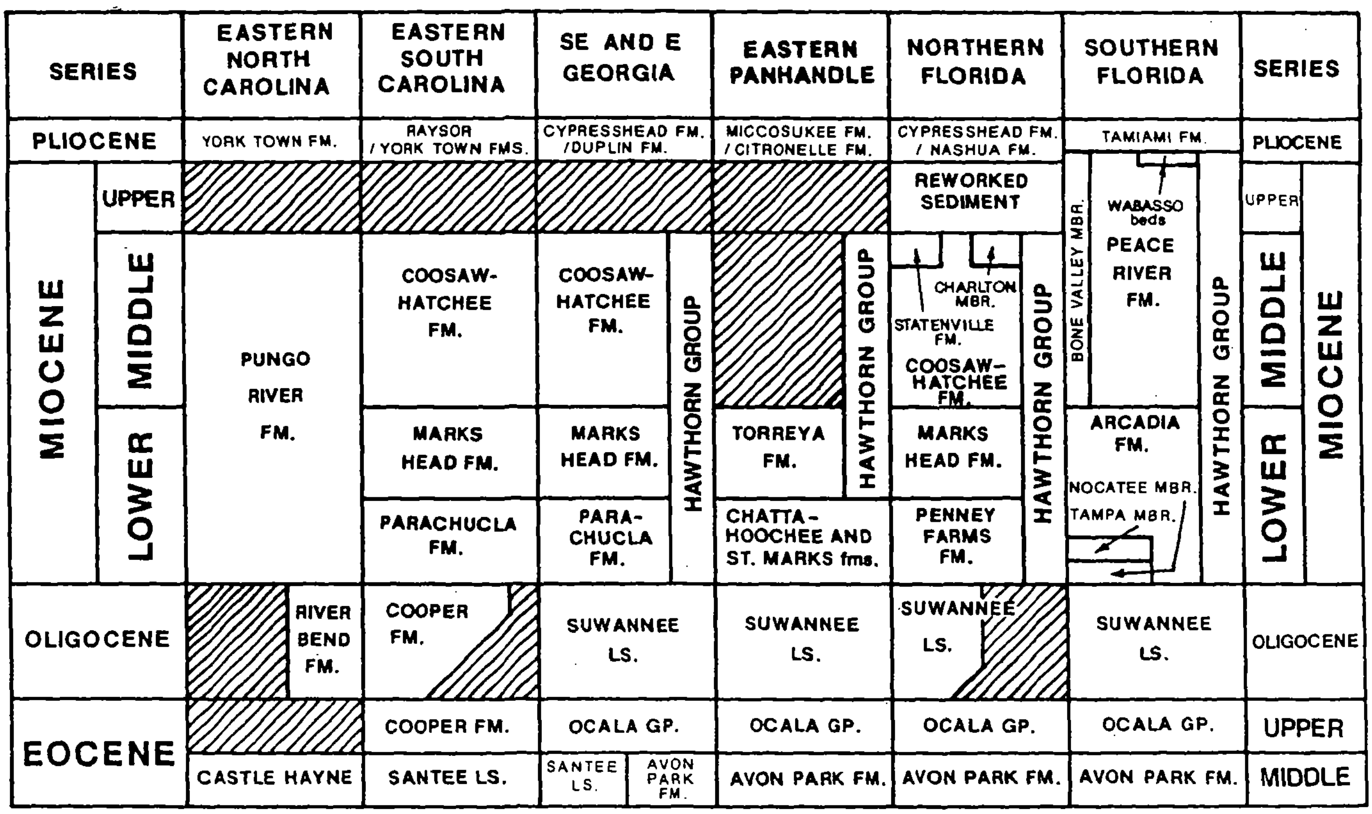


Figure 19. Formational correlations (modified from unpublished C.O.S.U.N.A. Chart, 1985).

The Penney Farms Formation of the Hawthorn Group is older than the commonly accepted age for the Hawthorn Formation as described by Puri and Vernon (1964). This age, Middle Miocene, was accepted for the Hawthorn Formation by the Florida Geologic Survey for sometime. The data presented here indicate this should be revised (see Figure 19). Armstrong et al. (1985) have even suggested a latest Oligocene age for the base of the Hawthorn in southeastern Florida.

Discussion

As stated previously, the Penney Farms Formation in northern Florida is equivalent to the Parachucla Formation in southeastern Georgia. The Penney Farms represents a southern extension of the Parachucla siliciclastics, but contains a significant amount of dolostone which is not present in the Parachucla. The two units are laterally gradational with each other. Within the gradational sequence the lateral boundary between the units is arbitrarily placed where carbonate becomes an important lithologic factor. This boundary usually occurs just north of the state line in Georgia; however, the Parachucla occurs in northernmost Nassau County, Florida. The Penney Farms Formation also grades laterally, to the south, into undifferentiated Hawthorn Group.

The carbonate section of the Penney Farms Formation has often been referred to as the basal Hawthorn dolostone in northern Florida. It is lithologically distinctive enough to be recognizable in well cuttings, even in relatively poor quality cuttings. The gamma-ray signature also is quite distinctive, consisting of a number of very high counts per second (cps) peaks (see section on gamma-ray logs).

The full areal extent of the Penney Farms deposition on the Ocala Platform is not presently known. The occurrence of sediments assigned to this unit at the Martin-Anthony road cut in Marion County (elevation 140 to 150 feet [43-46 meters] above MSL) suggest deposition on a significant portion of the platform.

MARKS HEAD FORMATION

Definition and Reference Section

Huddlestun (in press) reintroduced the Marks Head Formation as part of the Hawthorn Group in Georgia. The Marks Head Formation is extended here to encompass the middle unit of the Hawthorn Group in north Florida. The lithologic similarities between the Marks Head Formation in southeast Georgia and in north Florida warrants the use of the same nomenclature.

Huddlestun (in press) describes the type locality of the Marks Head Formation in Georgia from outcrops at and near Porters Landing in northern Effingham County, Georgia. The reader is referred to Huddlestun (in press) for descriptions of these localities and for a historical summary of the Marks Head Formation in Georgia.

The proposed reference section for the Marks Head Formation in Florida lies between -89 feet (-29 meters) MSL and -190 feet (-58 meters) MSL in the Jennings #1 core, W-14219, Clay County, Florida (SE¼, SE¼, Section 27, Township 4S, Range 24E) (Figure 20). The land surface elevation is 90 feet (27 meters) MSL.

Lithology

The Marks Head Formation in Florida consists of interbedded sands, clays and dolostones throughout its extent. Carbonate beds are more common in the Marks Head Formation in Florida than in Georgia; the proportion of carbonate, both as a rock type and an accessory (matrix) mineral, gradually increases into Florida. This unit is the most lithologically variable formation of the Hawthorn Group in north Florida. Miller (1978) defined his Unit D (equivalent to the Marks Head Formation) as being "complexly interbedded shell limestone, clay, clayey sand and fine grained sandstone." The variable nature of the Marks

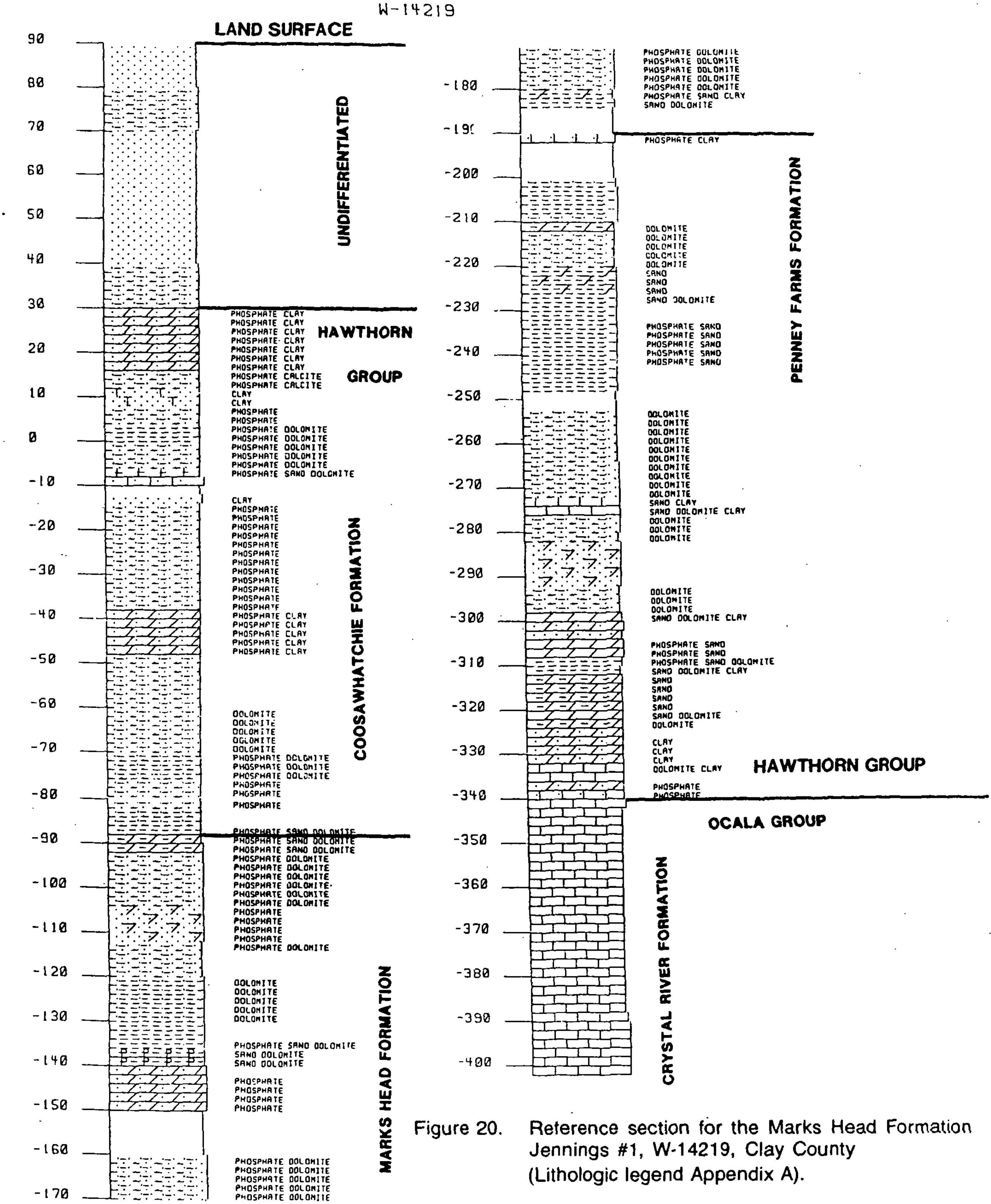


Figure 20. Reference section for the Marks Head Formation Jennings #1, W-14219, Clay County (Lithologic legend Appendix A).

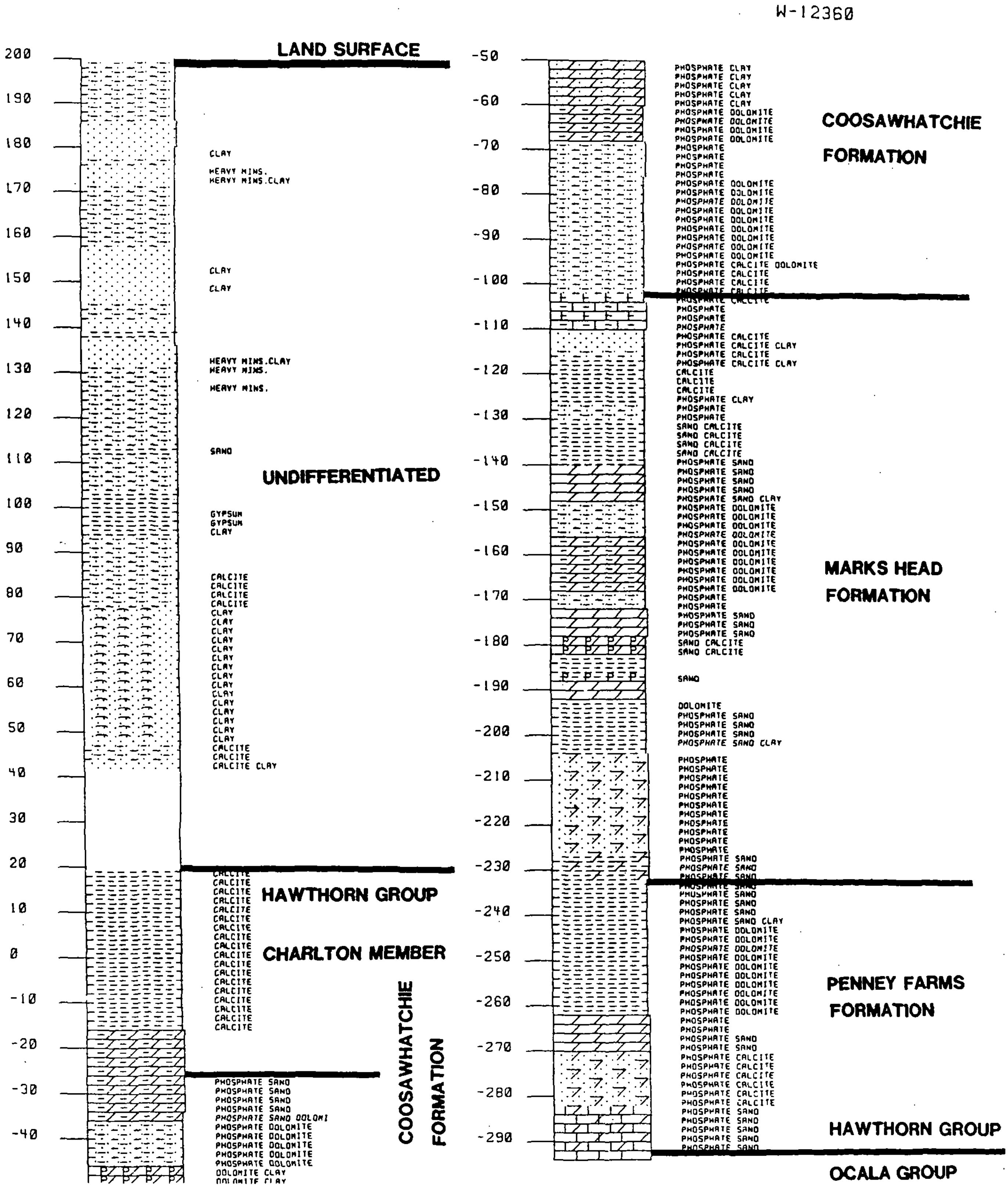


Figure 21. Reference section for the Marks Head Formation, N.L. #1, W-12360, Bradford County (Lithologic legend Appendix A).

Head is readily apparent when comparing the lithologic columns of W-14219 (Figure 20) and W-12360 (Figure 21).

The carbonate portion of the Marks Head Formation is typically dolostone; limestone is uncommon but does occur sporadically as is the case throughout the Hawthorn Group. The Marks Head dolostones are generally quartz sandy, phosphatic and clayey. The dolostones vary in induration from poorly consolidated to well indurated. The induration varies in inverse relationship to the amount of clay present within the sediment. Phosphate grains normally comprise up to 5 percent; however occasional beds may contain significantly higher percentages. Quartz sand content varies from less than 5 percent to greater than 50 percent where it grades into a dolomite cemented quartz sand. The dolostones range from yellowish gray (5 Y 7/2) to olive gray (5 Y 4/1) in color. Crystallinity varies from micro- to very finely crystalline with occasional more coarsely crystalline zones. Molds of mollusk shells are often present.

The occurrence of limestone within the Marks Head Formation in Florida is quite rare. The majority of the "limestone" reported from this part of the section by other workers is actually dolostone. The limestone that does occur is characteristically dolomitic, quartz sandy, phosphatic, clayey, and fine grained.

The quartz sands from the Marks Head Formation are generally fine to medium grained (occasionally coarse grained), dolomitic, silty, clayey and phosphatic. The dolomite, silt and clay contents are highly variable and the quartz sands are gradational with the other lithologies. Phosphate sand is usually present in amounts ranging from 1 to 5 percent; however, phosphate grain percentages may range considerably higher in thin and localized beds. The quartz sands are typically light gray (N 7) to olive gray (5 Y 4/1) in color. Induration varies from poor to moderate.

Clay beds are quite common in the Marks Head Formation, occasionally comprising a large portion of the section. The clays are quartz sandy, silty, dolomitic and phosphatic. As is the case in the Penney Farms Formation, the Marks Head clays contain highly variable percentages of accessory minerals; relatively pure clays do occur but are not common. The clays range from greenish gray (5 GY 6/1) to olive gray (5 Y 4/1) in color and are typically lighter colored than the clays of the underlying unit.

Phosphate grains are present virtually throughout the Marks Head Formation. They characteristically occur as brown to black, sand-sized grains scattered throughout the sediments. The phosphate grains are rounded and often in the same size range as the associated quartz sands. Phosphate pebbles occur rarely.

Mineralogically, the Marks Head Formation clays contain palygorskite, sepiolite, smectite and illite; kaolinite is present only in the weathered section (Hettrick and Friddell, 1984). Hettrick and Friddell (1984) indicated that palygorskite is often the dominant clay mineral in this unit; smectite is the second most abundant clay mineral. Smectite becomes the most abundant clay mineral when palygorskite content decreases. Other minor mineralogic constituents include mica, opal-ct, and feldspar. Huddlestun (in press) reports the occurrence of zeolite in the Marks Head Formation in Georgia.

The Marks Head Formation becomes difficult to identify in the southern portion of the area between the Sanford High and the Ocala Platform (Figure 22). Within this transition zone the Marks Head loses most of the dolostone beds. The distinction between this unit and the overlying Coosawhatchie Formation becomes problematic. As a result, the Hawthorn Group in this area is referred to as undifferentiated. Additional coring in the transition zone may delineate the facies changes through this zone and more accurately determine the correlation of this unit into central and south Florida.

Subjacent and Suprajacent Units

The Marks Head Formation is underlain disconformably throughout most of its extent by the Penney Farms Formation. The upper member of the Penney Farms Formation consists predominantly of darker, olive gray (5 Y 3/2) colored sands and clays with occasional dolostone beds. The base of the Marks Head Formation is placed at the contact between the darker colored sands and clays of the upper Penney Farms and the generally lighter colored, more complexly interbedded sands, clays and dolostone of the Marks Head. Occasionally, the contact is marked by a rubble zone containing phosphatized carbonate

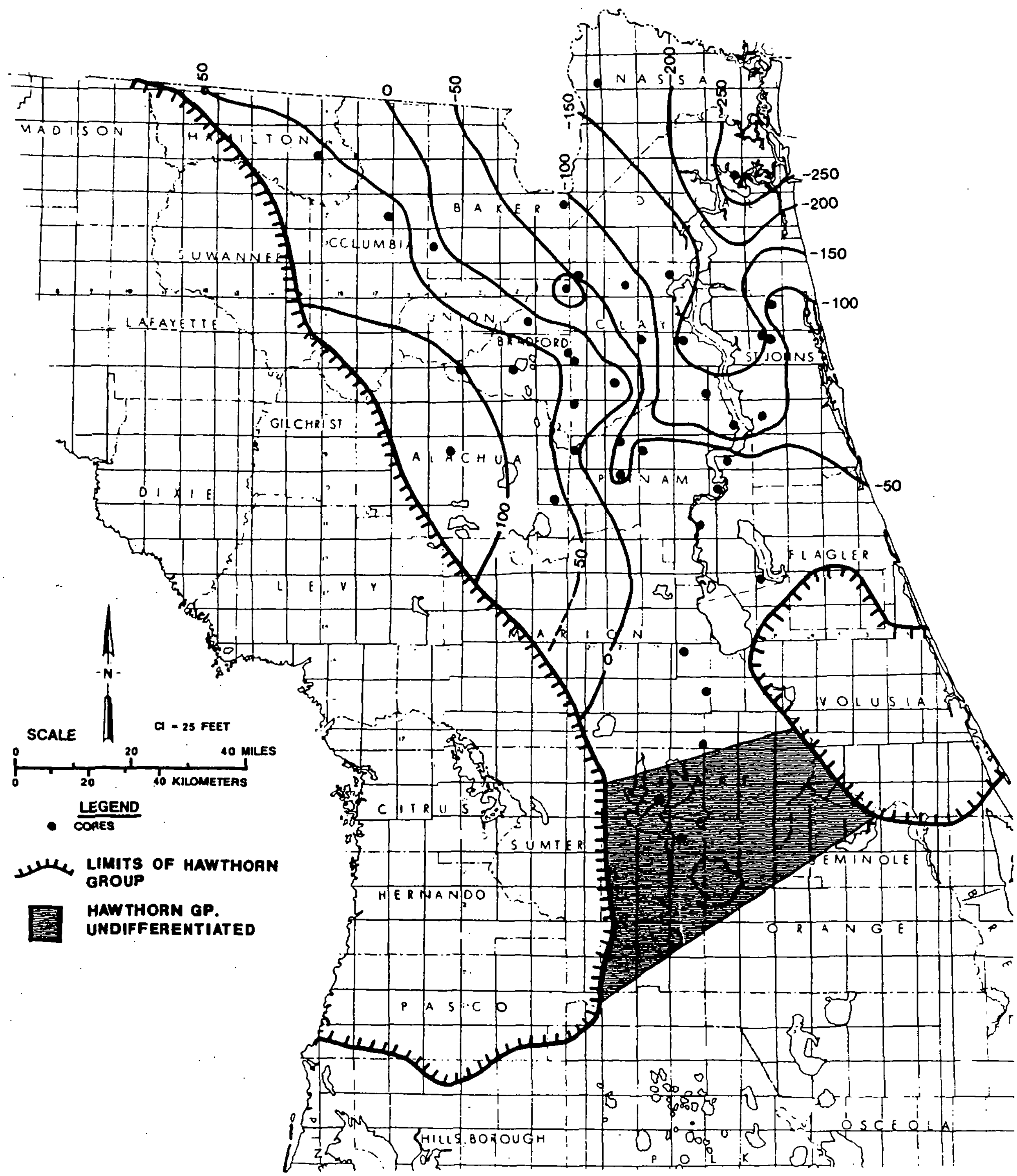


Figure 22. Top of the Marks Head Formation. Shaded area indicates undifferentiated Hawthorn Group.

clasts but the unconformity is often difficult to recognize in cores. In the western-most portion of Hamilton County, the Marks Head is underlain by the sandy carbonates of the Penney Farms Formation.

The Coosawhatchie Formation disconformably overlies the Marks Head Formation throughout north Florida except where it has been removed by erosion. In these areas the Marks Head is overlain by sediments referred to as undifferentiated, post-Hawthorn deposits.

The Coosawhatchie-Marks Head contact is generally placed at the top of the first hard carbonate bed or light colored clay unit below the darker colored clayey, dolomitic, quartz sands and dolostones of the basal Coosawhatchie Formation. Occasionally, the contact appears gradational in a sequence of dolostones and interbedded sands. In this case the top of the upper-most dolostone bed is regarded as the boundary. Occasionally a rubble bed marks the unconformity.

The relationship of the Marks Head Formation to the underlying and overlying units is graphically illustrated in Figures 11 through 16.

Thickness and Areal Extent

The Marks Head Formation of the Hawthorn Group in Florida occurs primarily as a subsurface unit. The top of the Marks Head Formation in the subsurface varies from -260 feet MSL (-79 meters) in Carter #1, W-14619, Duval County to +114 feet MSL (+35 meters) in Devil's Millhopper #1, W-14641, in Alachua County (Figure 22).

The Marks Head Formation dips to the northeast from the flanks of the Ocala Platform toward the Jacksonville Basin with an average dip of 4 feet per mile (0.8 meters per kilometer) (Figure 22). The direction of dip of the Marks Head Formation trends towards the north from the St. Johns Platform into the Jacksonville Basin (Figure 4). The direction and angle of dip may vary locally.

The thickness of the Marks Head Formation varies from being absent on the crest of the Ocala and Sanford Highs to 130 feet (40 meters) in N.L. #1, W-12360, Bradford County (Figure 23). It is interesting to note that this well is not in the Jacksonville Basin but to the southeast of it.

The Marks Head Formation is present throughout much of north Florida. It apparently has been removed by erosion from the Sanford High (Figures 4 and 23) and has not been identified on the Ocala Platform possibly being absent as a result of erosion or non-deposition. In the area between the Ocala and Sanford Highs, the Marks Head is very thin and becomes difficult to recognize, merging southward into the undifferentiated Hawthorn Group.

Age and Correlation

Dateable fossil assemblages within the Marks Head Formation have not been found in north Florida. The only fossils noted were scattered molds of mollusk shells and occasional diatom molds. Lithologic correlation between these sediments and those in Georgia, where fossiliferous sediments are found, indicates that the Marks Head Formation is late Early Miocene (Burdigalian) age (Huddlestun, personal communication, 1983). Planktonic foraminifera in Georgia indicate Zone N.6 or early N.7 of Blow (1969).

Huddlestun (in press) suggests that the Marks Head Formation in Georgia is correlative with the Torreya Formation (Banks and Hunter, 1973) in the eastern panhandle of Florida (Figure 19). Huddlestun (in press) considers both formations to be slightly older than the Chipola Formation in the Florida panhandle which has been correlated with the upper part of planktonic zone N.7 of Blow (1969). It is suggested here that the Marks Head Formation of north Florida is correlated with at least the upper part of the Arcadia Formation and is younger than the Arcadia's Tampa Member in southwest Florida. The Marks Head Formation is thought to be a time equivalent of the lower part of the downdip Bruce Creek Limestone in the southern part of the Apalachicola Embayment. It appears that the Marks Head Formation may be correlative with the lower Pungo River Formation in North Carolina, based on ages suggested for the Pungo River by Gibson (1982).

As is the case for the Penney Farms Formation, the Marks Head Formation is older (see Figure 19) than the previously accepted age for the "Hawthorn Formation" in Florida as interpreted by Cooke

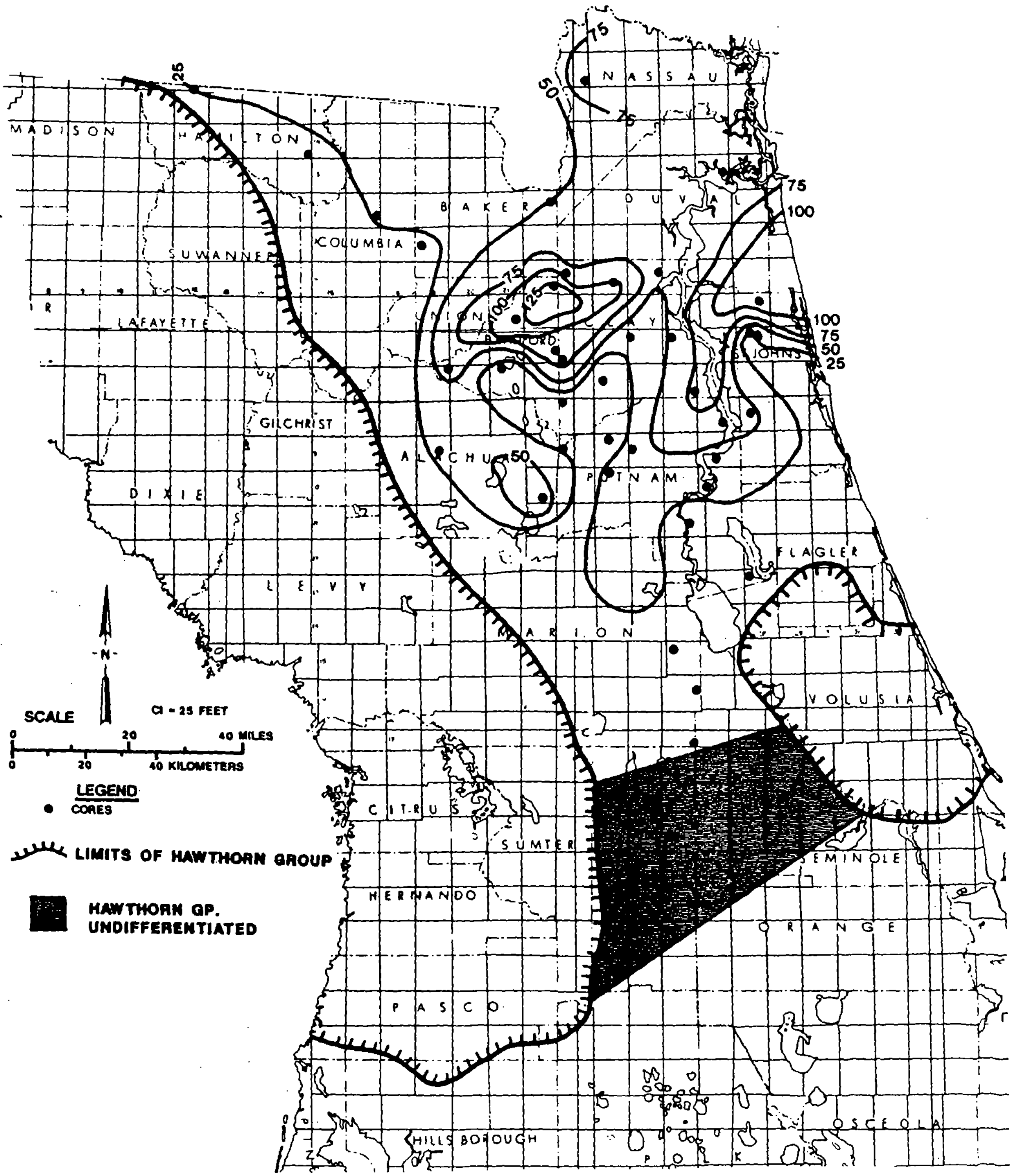


Figure 23. Isopach of Marks Head Formation. Shaded area indicates undifferentiated Hawthorn Group.

(1945) and Puri and Vernon (1964). Puri and Vernon suggested a strictly Middle Miocene age for their "Hawthorn."

Discussion

The extension of the name Marks Head Formation into Florida was based on the general lithologic similarities between the sediments in Georgia and those in Florida. Despite an increased carbonate content in the Florida section, the units are quite similar and the Georgia lithostratigraphic nomenclature is used to avoid stratigraphic confusion.

The Marks Head Formation, like the time-equivalent unit in the panhandle, the Torreya Formation, contains significant amounts of clay. As reported by Hetrick and Friddell (1984), palygorskite is generally the dominant clay mineral with subordinate amounts of smectite. The occurrence of large amounts of palygorskite is suggestive of an unusual set of environmental circumstances which prevailed over large areas of the southeastern coastal plain. The exact conditions are not well understood. However, whether palygorskite is a product of brackish water lagoons (Weaver and Beck, 1977) or ephemeral (alkaline) lakes (Upchurch, et al., 1982), the fluctuating sea levels in late Early Miocene could have reworked these deposits, incorporating vast amounts of palygorskite into the Marks Head sediments. Future detailed clay mineralogy investigations may facilitate a better understanding of the genesis of the clays and of the depositional environments of the Marks Head Formation.

COOSAWHATCHIE FORMATION

Definition and Reference Section

The Coosawhatchie Formation of the Hawthorn Group is used in this paper for the upper unit of the group in much of north Florida. Huddlestun (in press) proposed the Coosawhatchie as a formal lihtostratigraphic unit in Georgia. It extends into north Florida with only minor lithologic changes.

The Coosawhatchie Formation in Florida consists of three members: informal lower and upper members and the Charlton Member, as defined by Huddlestun (in press). The Charlton Member will be discussed separately. A basal clay bed occurs in a few cores in St. Johns County and may equate with the Berryville Clay (Huddlestun, in press).

The type locality for the Coosawhatchie Formation is at Dawsons Landing on the Coosawhatchie River in Jasper County, South Carolina, as described by Heron and Johnson (1966). Huddlestun (in press) suggests a reference locality in Georgia along the Savannah River in Effingham County.

The reference section for north Florida is in the Harris #1 core, W-13769, Clay County (SW¼, SE¼, Sec. 7, T6S, R25E) (Figure 24). The surface elevation of the core is 97 feet (30 meters) MSL. The top of the Coosawhatchie Formation in Harris #1 is at +37 feet (+11 meters) MSL (Figure 24), the base is at -74 feet (-23 meters) MSL.

Lithology

The Coosawhatchie Formation in Florida consists of quartz sands, dolostones and clays. Characteristically, sandy to very sandy dolostone is the most common lithology in the upper informal member, where it is interbedded with quartz sands and clays. In the lower informal member, the quartz sands and clays predominate with interbedded dolostones.

The quartz sands are dolomitic, clayey and phosphatic. The sand grains are fine to medium grained, poorly to moderately sorted, and subangular to subrounded. The proportions of accessory materials vary greatly. The sands grade into the dolostones and clays in many instances. The phosphate grain content is quite variable ranging from a trace to more than 20 percent. Clay content varies from less than 5 per-

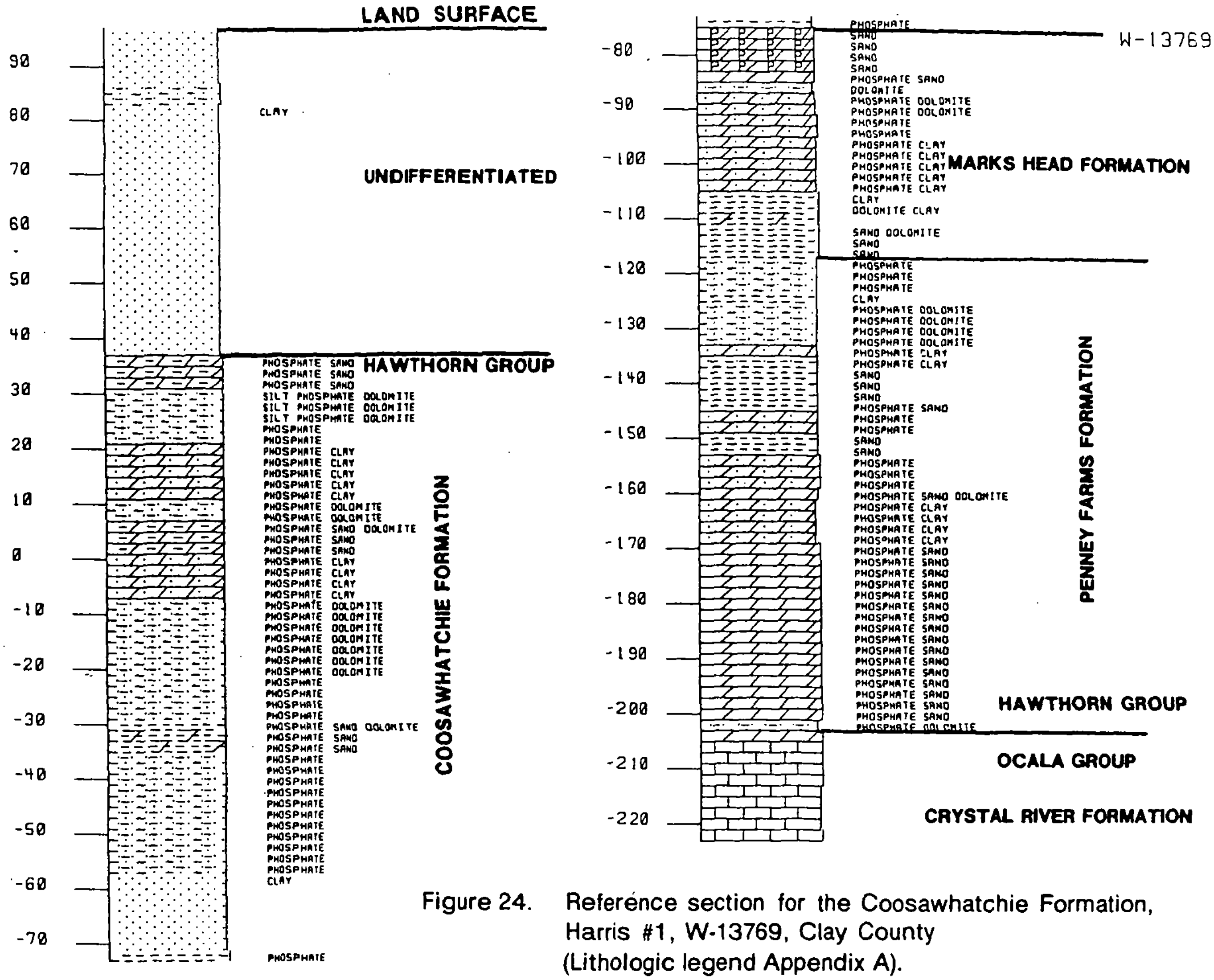


Figure 24. Reference section for the Coosawhatchie Formation, Harris #1, W-13769, Clay County (Lithologic legend Appendix A).

cent to greater than 30 percent. The sands are often lighter colored in the upper member where there is more carbonate in the matrix and darker in the lower member. Colors range from greenish gray (5 GY 6/1) and light gray (N 7) to olive gray (5 Y 4/1). Induration is generally poor.

The dolostones of the Coosawhatchie Formation are quartz sandy, clayey and phosphatic. The percentages of quartz sand and clay vary widely and may be as much as 50 percent in transitional zones. Phosphate grain content is quite variable also, but is generally less than 10 percent. The dolostones are micro- to fine crystalline, poorly to moderately indurated and occasionally contain molds of fossils. They range in color from light gray (N 7) and greenish gray (5 GY 6/1) to olive gray (5 Y 6/1). The dolostones of the upper member appear to become more calcareous in the Jacksonville Basin.

The clays in the Coosawhatchie Formation are typically quartz sandy, silty, dolomitic and phosphatic. The clays are light olive gray (5 Y 6/1) to olive gray (5 Y 4/1). Clay beds are most common in the lower member (Scott, 1983). The clay mineralogy is dominated by smectite (Hetrick and Friddell, 1984). The clay beds often contain diatoms (Hoenstine, 1984).

The phosphate grains present in the Coosawhatchie Formation are normally amber colored to brown or black; lighter colors occur near the land surface. The phosphate grains are usually well rounded and in

the same size range as the associated quartz sands. Coarser phosphate sands and phosphate pebbles or rubble are not common but are present.

Subjacent and Suprajacent Formations

The Coosawhatchie Formation disconformably overlies the Marks Head Formation but the disconformity is often not readily apparent. It is, however, recognized biostratigraphically in Georgia (Huddlestun, personal communication, 1983). The contact often occurs in a thin gradational sequence of interbedded sands and dolostones. Occasionally, the contact is marked by a rubble bed.

The Statenville Formation of the Hawthorn Group overlies and interfingers with the Coosawhatchie in Hamilton and Columbia Counties and possibly a small portion of Baker County. The contact is conformable and is recognized by the occurrence of more phosphate grains and less carbonate in the Statenville and the thin bedded nature of the Statenville.

With the exception of the area described above, the Coosawhatchie in Florida is overlain unconformably by undifferentiated post-Hawthorn deposits. These include sands, clays, shell beds and occasional limestones. The relationship of the Coosawhatchie to the underlying and overlying units is indicated in Figures 11 through 16.

Thickness and Areal Extent

The Coosawhatchie Formation occurs throughout much of north Florida. The top of the Coosawhatchie ranges from -93 feet MSL (-28 meters) in Bostwick #1, W-14477, Putnam County to +168 feet MSL (51 meters) in Devils Millhopper #1, W-14641, Alachua County (Figure 25). It attains a maximum thickness in Florida (including the Charlton Member) of 222 feet (68 meters) in Carter #1, W-14619, Duval County (Figure 26). The Charlton Member in this core is 23 feet (7 meters) thick. Huddlestun (in press) indicates that the Coosawhatchie attains a maximum thickness of 284 feet (87 meters) in the southeast Georgia Embayment.

The Coosawhatchie Formation dips in a northeasterly direction from the flanks of the Ocala Platform toward the Jacksonville Basin (Figures 4 and 26). From the St. Johns Platform it dips to the west off the structure and to the north into the Jacksonville Basin (Figures 4 and 26). The average dip is approximately 4 feet per mile (0.8 meters per kilometer). Variations in the angle and direction of dip are evident from Figures 11 through 16.

The Coosawhatchie Formation is not known to occur over the Ocala and Sanford Highs or in the immediately surrounding areas. This is thought to be due primarily to erosion; nondeposition may also have played a role. The Coosawhatchie extends from Georgia southward into central Flordia. In central Florida (between the Ocala and Sanford Highs) it becomes difficult to distinguish and is included in the undifferentiated Hawthorn Group.

Age and Correlation

Huddlestun (in press) suggests a Middle Miocene (Early Serravallian) age for the Coosawhatchie Formation based on planktonic foraminifera. Huddlestun placed it in Zone N.11 of Blow (1969).

Hoenstine (1984) studied diatoms from a few selected cores through the Hawthorn. He recognized a Middle Miocene assemblage in Florida sediments assigned in this paper to the Coosawhatchie Formation.

The Coosawhatchie Formation is thought to be correlative with the lower portion of the Intracoastal Limestone in the Apalachicola Embayment (Schmidt, 1984) and the lower Shoal River Formation in the Florida panhandle (Huddlestun, pers. comm., 1983). In the peninsular area of Florida, it appears to correlate with the lower part of the Peace River Formation of this paper. The Coosawhatchie was correlated with much of the Pungo River Formation in North Carolina by Gibson (1982) and Riggs (1984) (Figure 19).

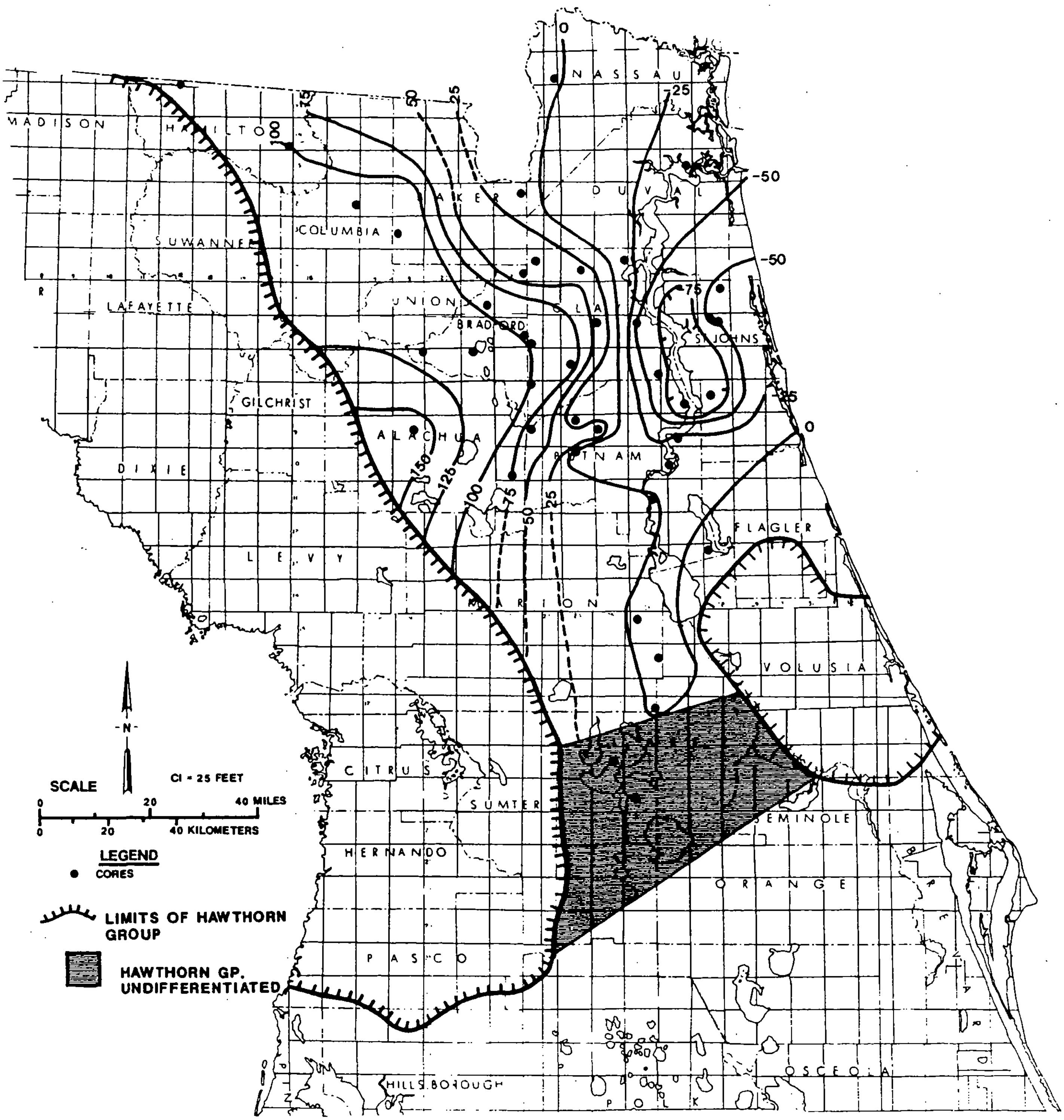


Figure 25. Top of Coosawhatchie Formation. Shaded area indicates undifferentiated Hawthorn Group.

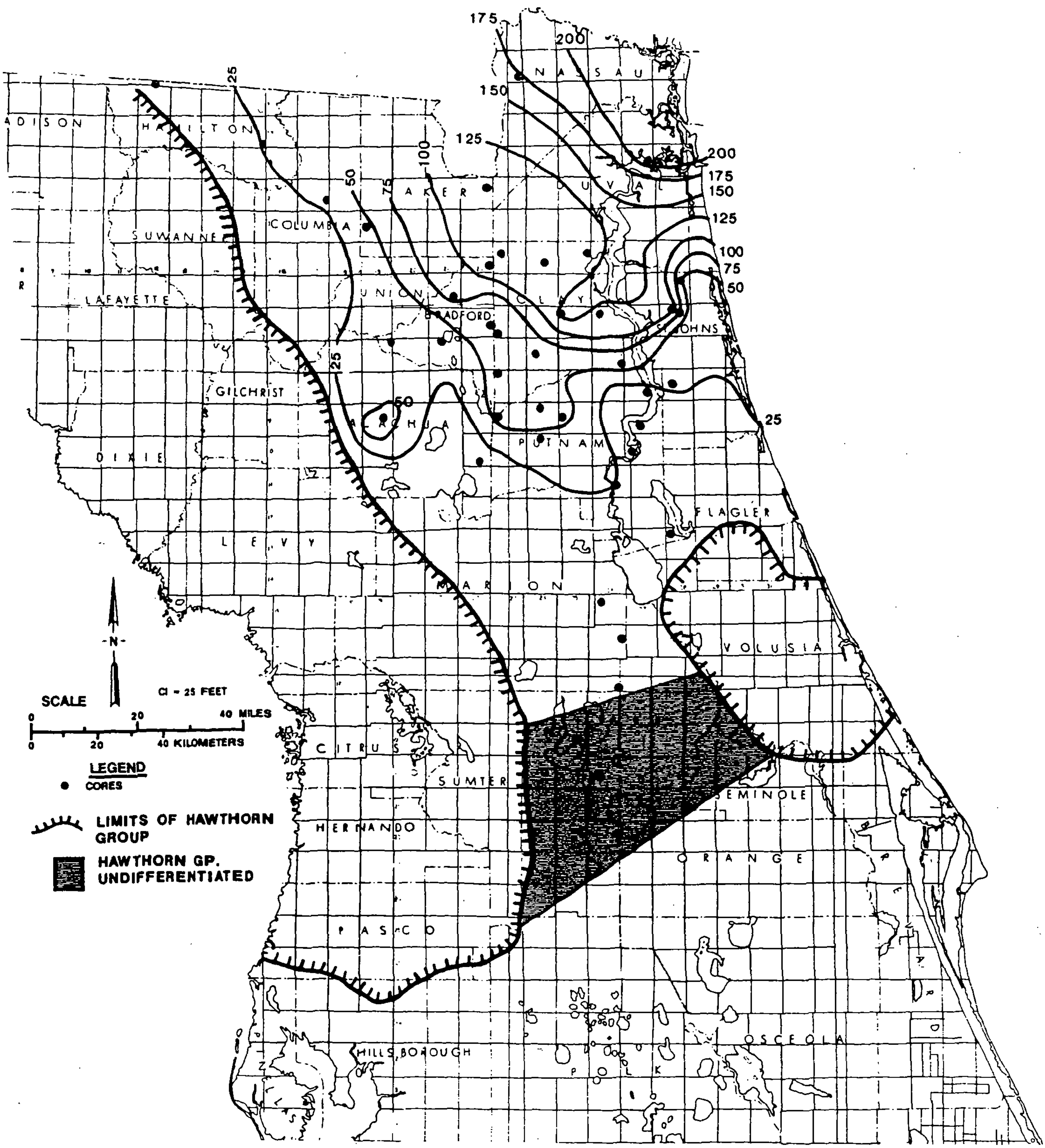


Figure 26. Isopach of Coosawhatchie Formation. Shaded area indicates undifferentiated Hawthorn Group.

Discussion

The Coosawhatchie Formation is widespread in northern Florida and throughout most of this area it is the uppermost Hawthorn sediment encountered in the subsurface. In limited areas it is shallow enough to be exposed in some foundation excavations. The Coosawhatchie Formation in the Jacksonville Basin contains a lower clay bed of variable thickness. This clay bed correlates with the Berryville Clay Member of the Coosawhatchie Formation in southeastern Georgia.

The Coosawhatchie Formation is quite similar to the Peace River Formation of southern Florida in that both are predominantly siliciclastic units. However, the Coosawhatchie contains significantly more carbonate in the matrix than the Peace River. The formations are gradational with each other through the zone of undifferentiated Hawthorn Group sediments in central Florida.

CHARLTON MEMBER OF THE COOSAWHATCHIE FORMATION

Definition and Reference Section

Huddlestun (in press) redefined the "Charlton formation" of Veatch and Stephenson (1911) as a formal member of the Coosawhatchie Formation in Georgia. He found that the Charlton Member is a lithofacies of the upper part of the Coosawhatchie (Huddlestun's Ebenezer Member) in south Georgia and north Florida. Huddlestun (in press) discussed the reference localities in some detail. A reference section for the Charlton Member of the Coosawhatchie Formation in Florida is the Cassidy #1 core, W-13815, Nassau County (NW¼, NW¼, Sec. 32, T3N, R24E). The surface elevation is 80 feet (24 meters) MSL. The Charlton Member occurs from +3 feet (+1 meter) MSL to -43 feet (-13 meters) MSL (Figure 27).

Lithology

The Charlton Member characteristically consists of interbedded carbonates and clays. It is less sandy than the upper member of the Coosawhatchie, into which it grades laterally and vertically and typically contains less sand and phosphate grains. It contains a clay component that is often very conspicuous in the cores (Huddlestun, in press). This has been found to be true in Florida also.

The carbonate beds of the Charlton Member are often dolostones but range into limestone. They are slightly sandy, slightly phosphatic to non-phosphatic and clayey. They often contain abundant molds of fossil mollusks. The dolostones are finely crystalline, light olive gray (5 Y 6/1) and poorly to moderately indurated. The limestones are characteristically very fine grained, slightly sandy, clayey, poorly to moderately indurated, and yellowish gray (5 Y 8/1).

The clays are dolomitic to calcareous, with poor to moderate induration, silty, and light gray (N 7) to greenish gray (5 GY 6/1). The clay minerals present include smectite, palygorskite, illite and kaolinite (Hetrick and Friddell, 1984).

Subjacent and Suprajacent Units

The Charlton Member both overlies and interfingers laterally with the upper informal member of the Coosawhatchie Formation. The Charlton is simply a distinctive facies of the upper informal member. The Charlton is disconformably overlain by the sediments discussed as overlying the Coosawhatchie Formation.

Thickness and Areal Extent

Sediments assigned to the Charlton occur at Brooks Sink (SW¼, SW¼, Sec. 12, T7S, R20E, Bradford

W-13815

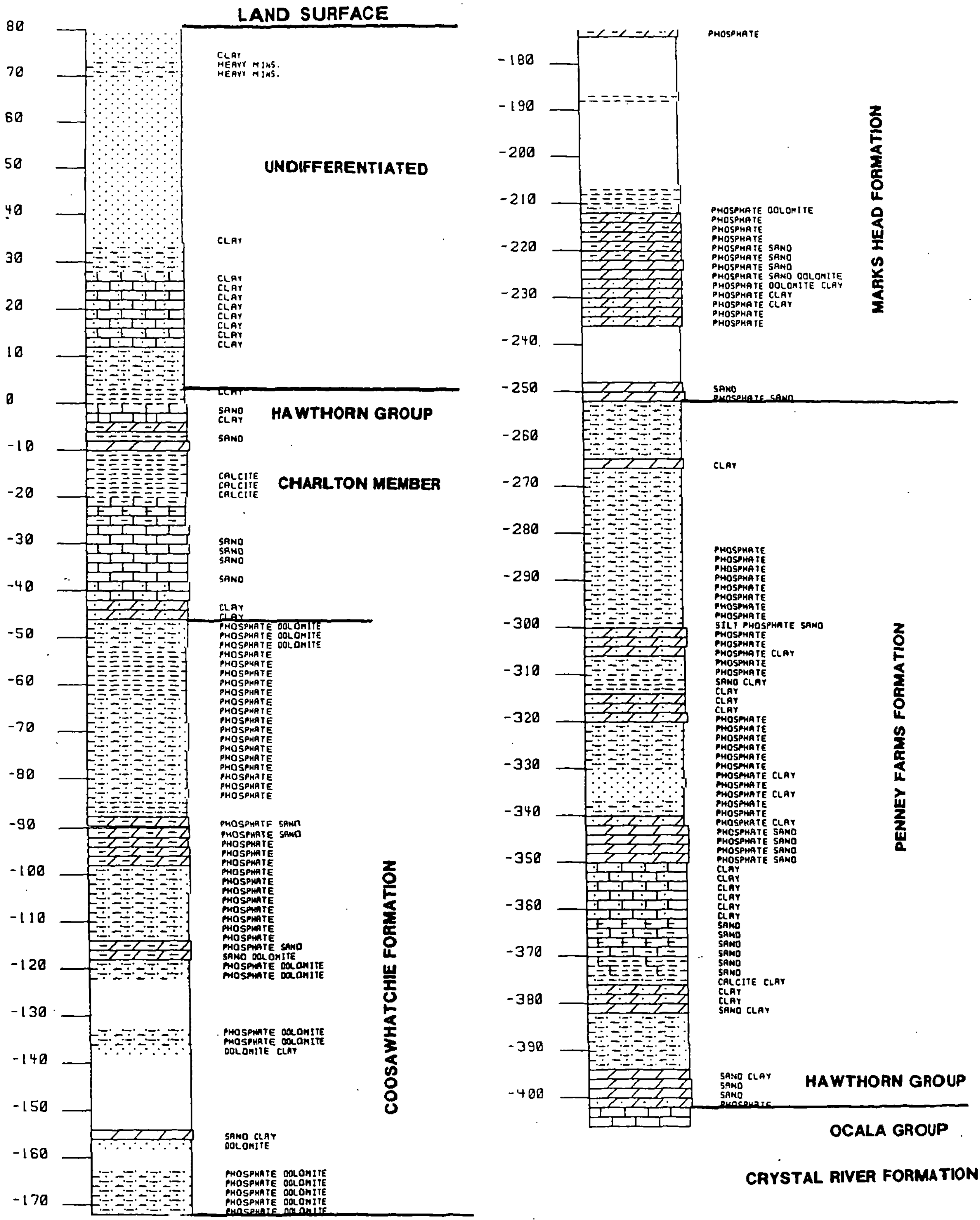


Figure 27. Reference core for the Charlton Member of the Coosawhatchie Formation, Cassidy #1, Nassau County (Lithologic legend Appendix A).

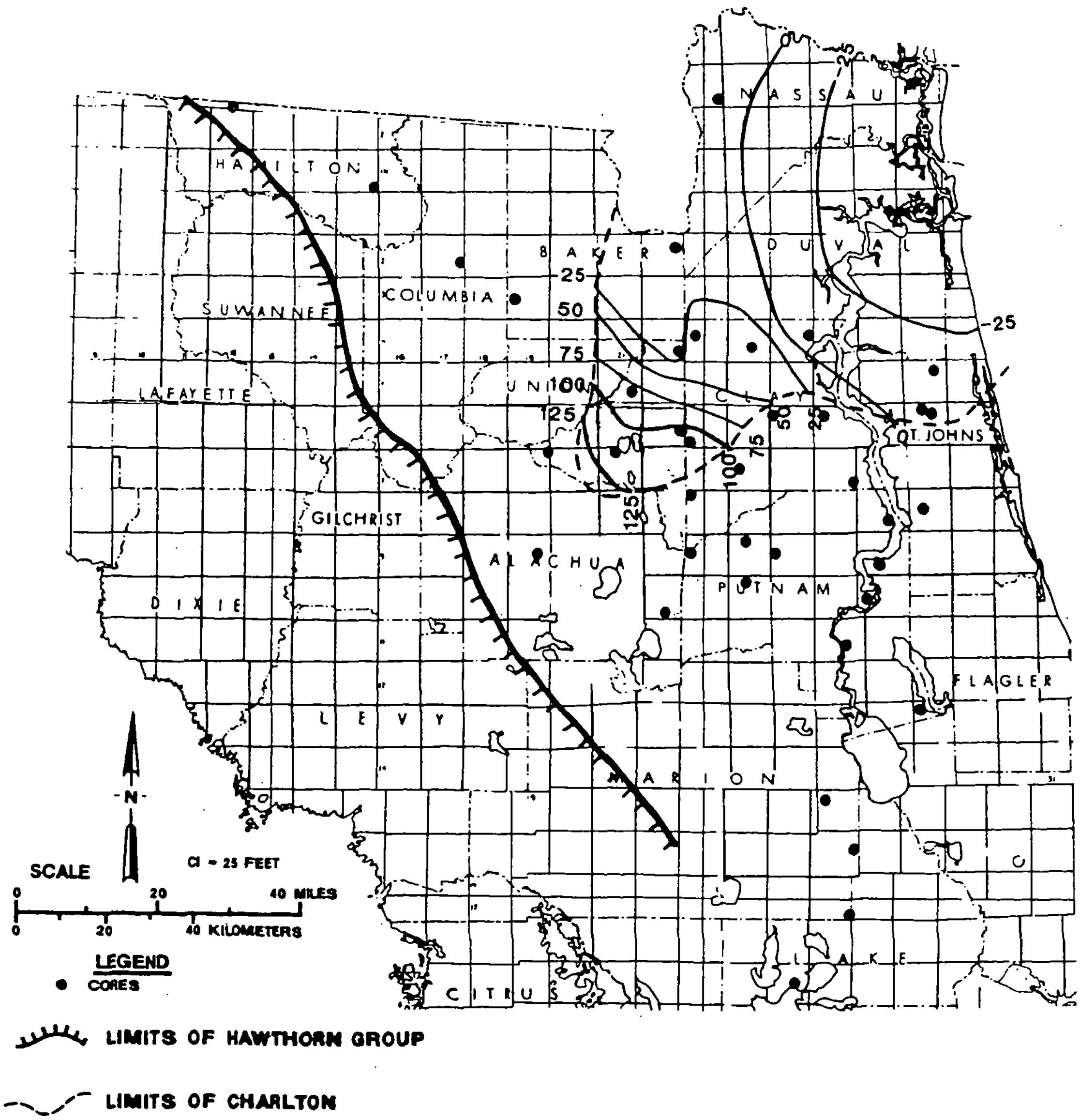


Figure 28. Top of the Charlton Member (dashed line indicates extent of Charlton).

County) at an elevation of +145 feet (44 meters) MSL (Figure 28). The highest elevation for the top of the Charlton in a core was in Wainwright #1, W-14283, Bradford County where it occurred at +109 feet (+33 meters) MSL. The deepest that the top of the Charlton Member was found is in Carter #1, W-14619, Duval County, where it is -38 feet MSL (-12 meters).

The Charlton Member of the Coosawhatchie Formation reaches its maximum recognized thickness in Florida in Cassidy #1, W-13815, Nassau County, where it is 40 feet (13 meters) thick (Figure 29). It is very spotty in its occurrence, as is evident from the cross-sections (Figures 11 through 16).

Age and Correlation

The Charlton Member, as originally defined by Veatch and Stephenson (1911), was considered Pliocene. Huddlestun (in press) postulates that, based on his observations of the molluskan fauna and

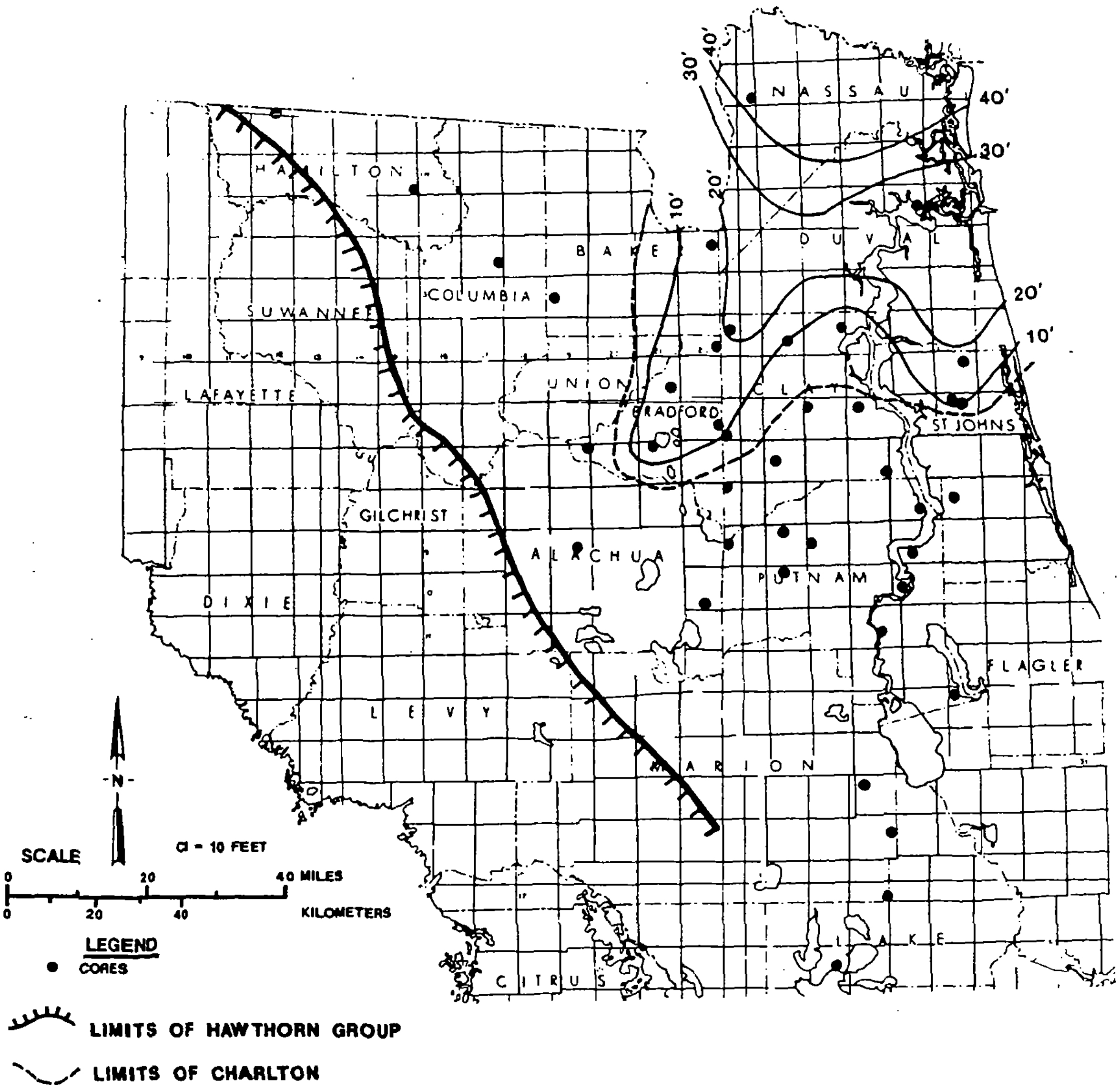


Figure 29. Isopach of the Charlton Member (dashed line indicates extent of Charlton).

the lithostratigraphy of the unit, it is Middle Miocene (Seravallian) in age (Figure 19).

The Charlton Member correlates with at least part of the informal upper member of the Coosawhatchie Formation. Correlations for the Coosawhatchie Formation are discussed in the previous section.

Discussion

The sediments assigned to the Charlton Member of the Coosawhatchie Formation were referred to as the "Jacksonville limestone" by Dall and Harris (1892). Dall and Harris suggested that the "Jacksonville limestone" was Pliocene in age. Matson (1915) changed the Jacksonville Limestone to the "Jacksonville formation." Cooke (1945) suggested placing the "Jacksonville formation" in the Duplin Marl. No type section was ever formally designated for the Jacksonville formation.

The lithologic relationship of these sediments to the rest of the Coosawhatchie Formation as recogniz-

ed in this study supports the work of Huddlestun (in press). The use of the Charlton Member rather than reintroducing the "Jacksonville limestone (or formation)" is suggested here to aid in nomenclatural consistency between the Georgia coastal plain and peninsular Florida. The reduction in status of the Charlton is necessary due to its limited extent.

STATENVILLE FORMATION

Definition and Type Location

The Statenville Formation is a new lithostratigraphic name proposed by Huddlestun (in press) for interbedded phosphatic sands, dolostones and clays at the top of the Hawthorn Group in the type section along the Alapaha River near Statenville, Georgia, north of Georgia Highway 94. The Statenville Formation extends southward into Hamilton and Columbia Counties area of Florida.

Reference localities listed by Huddlestun (in press) include exposures along the Alapahoochee Creek between the Georgia Highway 135 bridge in southwest Echols County and at the bridge over the river 1.25 miles (2 km) northeast of Jennings in Hamilton County, Florida; and exposures along the Suwannee River approximately one mile (1.6 km) above and below the site of the former Cones Bridge (now a boat landing) in Sec. 36, T1N, R16E in Hamilton and Columbia Counties, Florida. None of these outcrop sections expose the entire unit. The best section available is present in the designated reference core Betty #1, W-15121, Hamilton County (NE¼, NW¼, Sec. 3, T2N, R12E), Florida. This core provides the only complete section available. The Statenville Formation extends from the surface to 87 feet (26 meters) MSL. Surface elevation is 150 feet (46 meters) MSL (Figure 30).

Lithology

The Statenville Formation of the Hawthorn Group consists of interbedded sands, clays and dolostones with common to abundant phosphate grains. The diagnostic feature of the Statenville Formation is its thin bedded, often crossbedded, nature that is exhibited in outcrop (Figure 31). Outcrops generally consist of thin beds of dolostone and clay alternating with thin beds of sand.

Quartz sands predominate in much of the unit. The sands are fine to coarse grained (with occasional quartz gravel present), clayey to dolomitic, poorly indurated, poorly to moderately sorted, and subangular to angular. Colors range from very light gray (N 8) to light olive gray (5 Y 6/1). The sands are quite phosphatic with thin zones grading into phosphorite sands. The average phosphate grain percentage is approximately 10 percent.

The dolostones, which occur commonly as thin beds within the Statenville, are sandy, clayey, phosphatic and poorly to well indurated. The dolostones are typically yellowish gray (5 Y 8/1) to very light orange (10 YR 8/2). The percentages of sand, phosphate, and clay in the dolomites vary widely. Sediments in the Betty #1 core indicate that dolostone is most common in the lower portion of the unit.

Clay beds are not readily apparent in the outcrop sections. However, in the Betty #1 core they are quite common and are more abundant in the upper portion of the Statenville (Figure 30). The clay beds are characteristically sandy, dolomitic, phosphatic, light olive gray (5 Y 6/1) to yellowish gray (5 Y 8/1) and poorly indurated. The clay minerals present are characteristically smectite, palygorskite and illite.

Phosphate grains are abundant in the Statenville Formation. The phosphate grains are tan, amber, and brown to black, rounded, and generally are in a similar size range as the associated quartz sands. Huddlestun (in press) discusses phosphate pebbles and clasts (conglomerate) as being present in dolomite beds along the Suwannee River and also along the Alapaha River. Phosphorite from the Statenville Formation is presently being mined by Occidental Chemical Company in Hamilton County, Florida. These phosphorite sands occur in the upper, less dolomitic portion of the unit.

The thin bedded nature of the Statenville sediments is quite distinctive in outcrop. Huddlestun (in press) reports that the bedding ranges from horizontal to undulatory to variously cross bedded, with

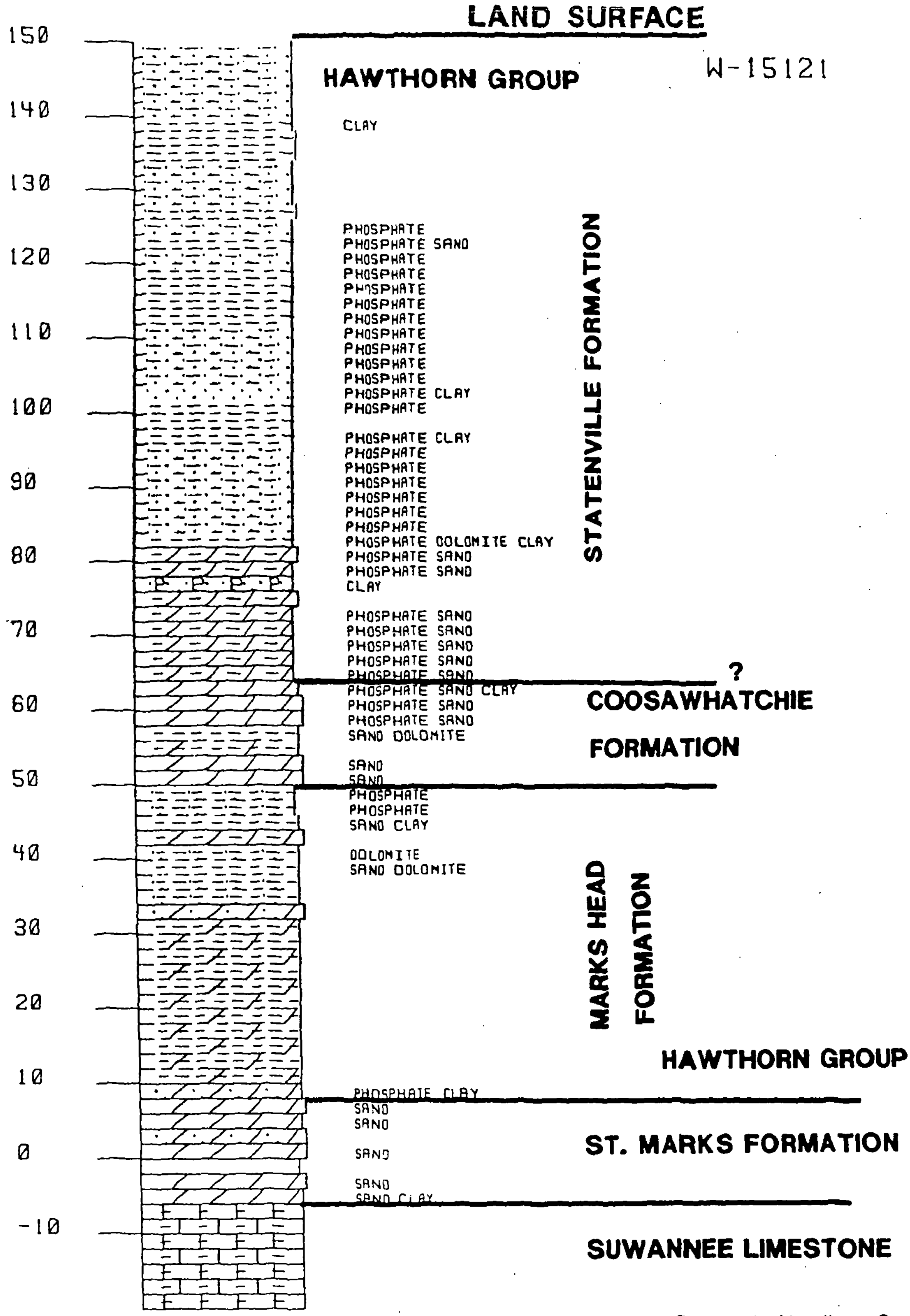


Figure 30. Reference core for the Statenville Formation, W-15121, Betty #1, Hamilton County (Lithologic legend Appendix A).

Figure 31. Photograph of Statenville Formation outcrop showing distinct cross bedding.

locally common cut and fill structures. The thin dolostone and clay beds remain as small ledges while the sands erode deeper into the outcrop (Figure 31). This distinctive bedding is also exposed in the phosphate pits in Hamilton County. A reworked zone with more parallel bedding is present above the crossbedded and thinbedded section.

Subjacent and Suprajacent Units

The Statenville Formation is underlain throughout its extent in north Florida by the Coosawhatchie Formation with which it also interfingers. The contact between the formations is conformable. The contact is placed at the base of the section of thinbedded, significantly (>15 percent) phosphatic sands, clays and dolostones.

The Statenville Formation occurs from very near the ground surface to the top of the Coosawhatchie Formation throughout most of its occurrence. The uppermost portion of the section is often weathered and has lost its dolomite and phosphate content. Near its eastern limit, it may be overlain by undifferentiated post-Hawthorn deposits (Figures 11 through 16).

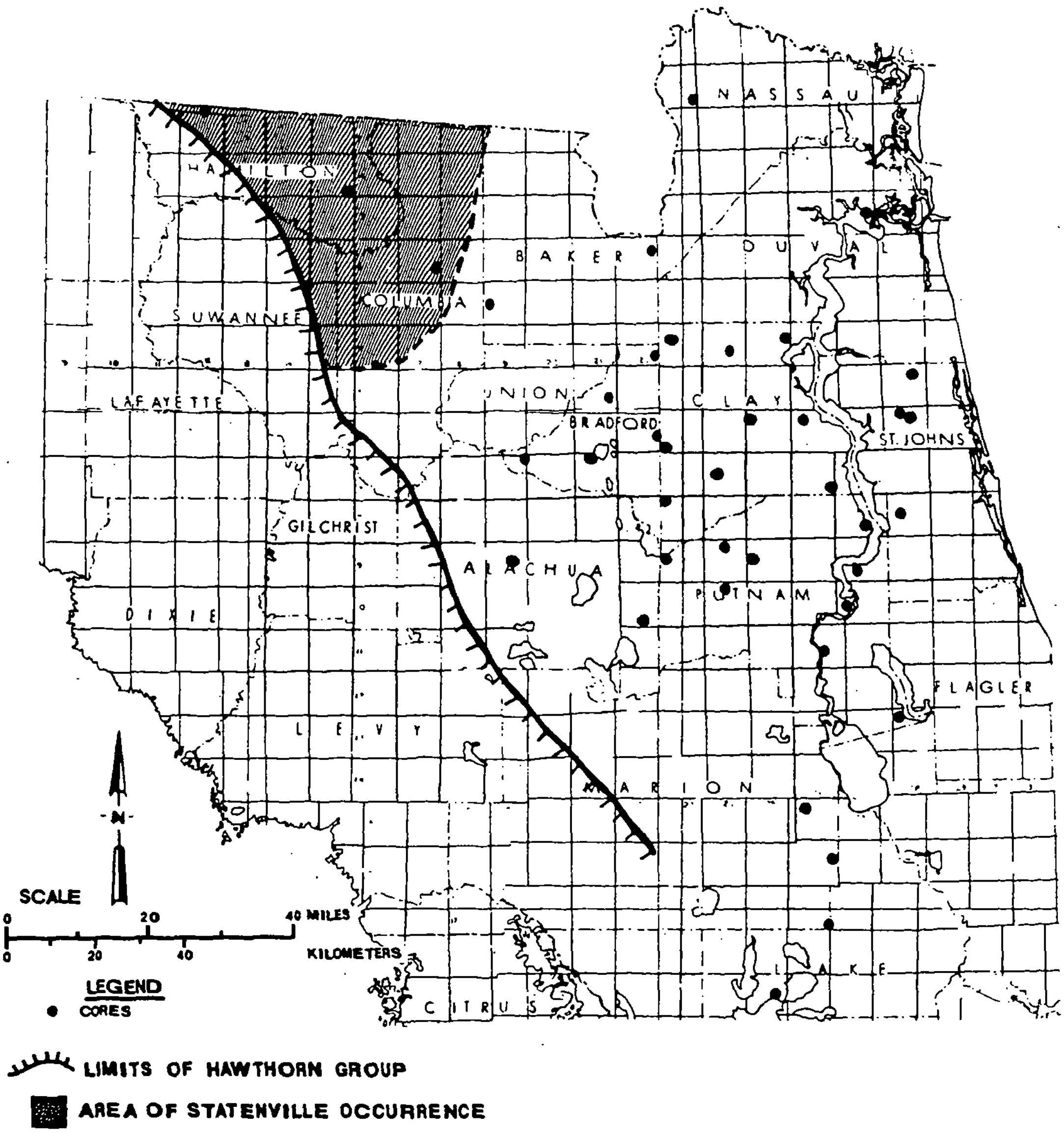


Figure 32. Area of occurrence of the Statenville Formation.

Thickness and Areal Extent

The Statenville Formation is recognized in three cores in north Florida (Figure 32). It also crops out along rivers and streams in the Hamilton and Columbia County area. Figure 32 shows the area where the Statenville is known to be present; lateral limits of the formation are poorly defined at this time.

The thickness of the Statenville Formation ranges up to 87 feet (26.5 meters) as recognized in Betty #1, W-15121, Hamilton County. This represents the greatest known thickness.

Age and Correlation

Brooks (1966) believed that these sediments were Late Miocene in age based on what he referred to as inconclusive paleontologic evidence. Limited collections of terrestrial vertebrate fossils from the Staten-

ville Formation indicate a Middle Miocene age (Huddlestun, in press). Webb (personal communication, 1983 *in* Huddlestun, in press) states that the Statenville mammal fauna is late Barstovian (late Middle Miocene) and is between 14 million and 12 million years old. Huddlestun (in press) believes this unit to be of Serravallian age, possibly in part equivalent to Zone N.11 of Blow (1969). The reworked zone at the top of the Statenville section appears to be Late Miocene based on vertebrate fossils (Cathcart, 1985, personal communication).

The Statenville Formation appears equivalent to the upper part of the Coosawhatchie Formation. Huddlestun's (in press) zonal correlation indicates an equivalence to the upper part of the Pungo River Formation in North Carolina. The Statenville is also correlative with part of the Intracoastal Formation in the Florida panhandle (Schmidt, 1984) and part of the Peace River Formation in southern Florida.

Discussion

The Statenville Formation of northern Florida is recognized primarily in outcrops along the Alapaha and Suwannee Rivers in Hamilton County and northward into Georgia. The Statenville's limited extent in north Florida is at least in part due to a rather limited data base. Additional cores and further research will be necessary to better define the limits and relationships of the Statenville and associated units.

ALACHUA FORMATION

The Alachua Formation, originally called the "Alachua clays" by Dall and Harris (1892), is an often misused and misunderstood unit. The original definition included sands and clays filling in karst depressions or stream channels related to sinkholes.

Sellards (1914) greatly expanded the definition of the Alachua Formation by including the hardrock phosphate-bearing deposits of the "Dunnellon formation" in the Alachua. He felt that the sands of the "Dunnellon" were a facies of the "Alachua clays." Later authors (Cooke and Mossom, 1929; Cooke, 1945) followed the expanded definition of the Alachua.

Vernon (1951) discussed the Alachua as "a mixture of interbedded, irregular deposits of clay, sand and sandy clay of the most diverse characteristics." Puri and Vernon (1964) also used this definition.

Discussions of the origin of the Alachua Formation have yielded a number of theories. Cooke (1945) believed that this unit was a residual, *in situ* accumulation of weathered Hawthorn sediments. Puri and Vernon (1964) felt the Alachua Formation was terrestrial and in part lacustrine and fluviatile. Brooks (1966, *in* Teleki, 1966) suggested that the Alachua was formed by deposition in an estuarine environment and included residual Hawthorn deposits overlain by slumped Pliocene fluvial and sinkhole accumulations. Based on the occurrence of the hard rock phosphates, the paleoextent of the Hawthorn Group sediments (Scott, 1981), field inspection of outcrops and the existing literature, the present author feels that this unit resulted from the weathering and/or reworking of Hawthorn Group sediments. The Alachua Formation at this time is not considered as part of the Hawthorn Group in peninsular Florida.

Suggested ages of the Alachua Formation range from as old as Middle Miocene (Vernon, 1951) to as young as Plio-Pleistocene (Pirkle, 1956b). The range in suggested ages can be attributed to a multiple phase development for this deposit. For example, different generations of karst or different cycles of reworking can incorporate similar lithologic packages with differing vertebrate faunas enclosed. As a result sediments assigned to the Alachua Formation may range in age from the Miocene to the Pleistocene.

It is readily apparent that the Alachua Formation is a complex unit. Further research is necessary to better understand and delineate this complex unit.

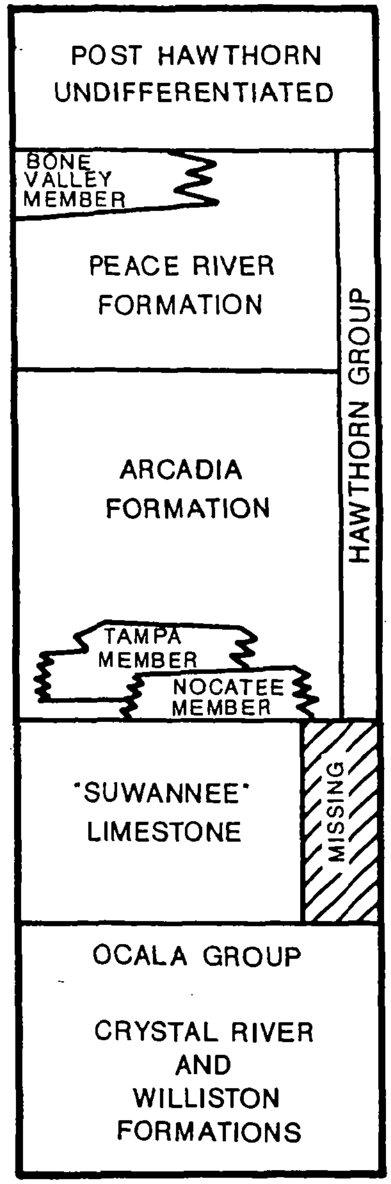


Figure 33. Lithostratigraphic units of the Hawthorn Group in southern Florida.

SOUTH FLORIDA

Although the Hawthorn Group in south Florida consists of the same general sediment types (carbonate, quartz sand, clay and phosphate), the variability and complexity of the section is different from the strata in northern Florida. In the south Florida area (Figure 1), particularly the western half of the area, the Hawthorn Group consists of a lower, predominantly carbonate unit and an upper, predominantly siliciclastic unit. Eastward the section becomes more complex due to a greater percentage of siliciclastic beds present in the lower portion of the Hawthorn Group.

The differences that exist between the northern and southern sections of the Hawthorn Group require separate formational nomenclature. In southern Florida, the Hawthorn Group consists of in ascending order, the Arcadia Formation (new name) with the Tampa and Nocatee (new name) Members and the Peace River Formation (new name) with the Bone Valley Member (Figure 33). The new nomenclature helps alleviate many of the previously existing problems associated with the relationship of the Bone Valley, Tamiami, Hawthorn, and Tampa units in the south Florida region.

ARCADIA FORMATION

Definition and Type Section

The Arcadia Formation is a new formational name proposed here for the lower Hawthorn carbonate section in south Florida. This unit includes sediments formerly assigned to the Tampa Formation or Limestone (King and Wright, 1979) and the "Tampa sand and clay" unit of Wilson (1977).

Dall and Harris (1892) used the term "Arcadia marl" to describe beds along the Peace River. This term was never widely used and did not appear in the literature again except in reference to Dall and Harris. It appears that their use of the "Arcadia marl" described a carbonate bed now belonging in the Peace River Formation of the upper Hawthorn Group. Riggs (1967) used the term "Arcadia formation" for the carbonate beds often exposed at the bottom of the phosphate pits in the Central Florida Phosphate District. Riggs' use of this name was never formalized. The "Lexicon of Geologic Names" (U.S.G.S., 1966) listed the name Arcadia as being used as a member of the Cambrian Trempealeau Formation in Wisconsin and Minnesota, thereby precluding its use elsewhere. Investigations into the current status of this name indicated that the Arcadia member has not been used in some 25 years and does not fit the current Cambrian stratigraphic framework. The Lexicon also indicates Arcadia clays as an Eocene (Claibornian) unit in Louisiana. This name also has been dropped from the stratigraphic nomenclature of Louisiana (Louisiana Geological Survey, 1984, personal communication). Since these former usages of this name are no longer viable, the term can be used for the lower Hawthorn Group sediments in southern Florida in accordance with Article 20 of the North American Code of Stratigraphic Nomenclature (NACSN, 1983).

The Arcadia Formation is named after the town of Arcadia in DeSoto County, Florida. The type section is located in core W-12050, Hogan #1, DeSoto County (SE¼, NW¼, Section 16, Township 38S, Range 26E, surface elevation 62 feet (19 meters)) drilled in 1973 by the Florida Geological Survey. The type Arcadia Formation occurs between -97 feet MSL (-30 meters MSL) to -520 feet MSL (-159 meters) (Figure 34).

Two members can be recognized within the Arcadia Formation in portions of south Florida. These are the Tampa Member and the Nocatee Member (Figure 33). The members are not recognized throughout the entire area. When the Tampa and Nocatee are not recognized, the section is simply referred to as the Arcadia Formation.

Lithology

The Arcadia Formation, with the exception of the Nocatee Member, consists predominantly of limestone and dolostone containing varying amounts of quartz sand, clay and phosphate grains. Thin beds of quartz sand and clay often are present scattered throughout the section. These thin sands and clays are generally very calcareous or dolomitic and phosphatic. Figure 34 graphically illustrates the lithologies of the Arcadia Formation including the Tampa and Nocatee Members. The lithologies of the

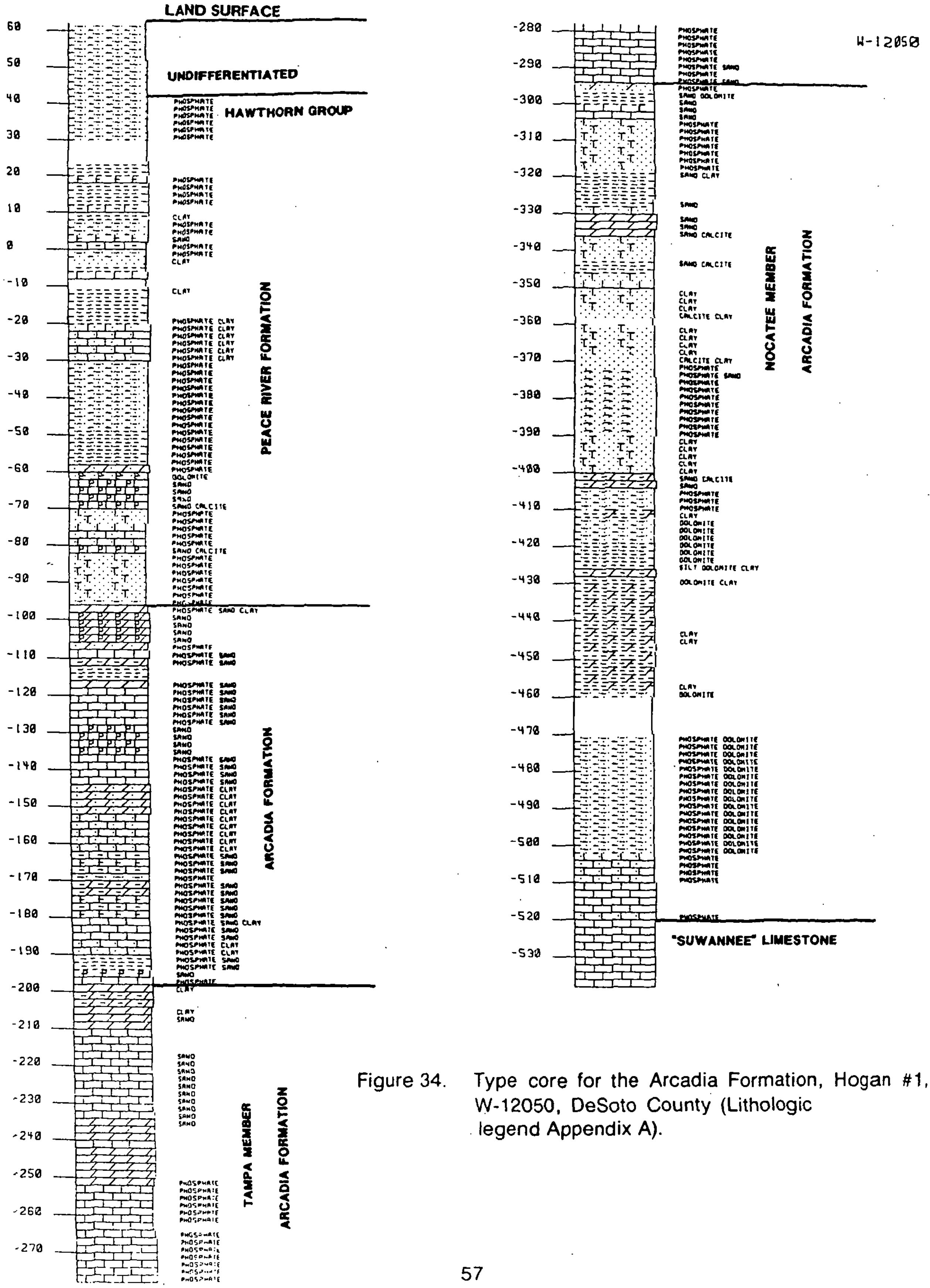


Figure 34. Type core for the Arcadia Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

Tampa and Nocatee Members will be discussed separately from the undifferentiated Arcadia Formation.

Dolomite is generally the most abundant carbonate component of the Arcadia Formation except in the Tampa Member. Limestone is common and occasionally is the dominant carbonate type. The dolostones are quartz sandy, phosphatic, often slightly clayey to clayey, soft to hard, moderately to highly altered, slightly porous to very porous (moldic porosity) and micro- to fine crystalline. The dolostones range in color from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). The phosphate grain content is highly variable ranging up to 25 percent but is more commonly in the 10 percent range. The limestones of the Arcadia are typically quartz sandy, phosphatic, slightly clayey to clayey, soft to hard, low to highly recrystallized, variably porous and very fine to fine grained. The limestones are typically a wackestone to mudstone with few beds of packstone. They range in color from white (N 9) to yellowish gray (5 Y 8/1). The phosphate grain content is similar to that described for the dolostones. Fossils are generally present only as molds in the carbonate rocks.

Clay beds occur sporadically throughout the Arcadia Formation. They are thin, generally less than 5 feet thick, and of limited areal extent. The clays are quartz sandy, silty, phosphatic, dolomitic and poorly to moderately indurated. Color of the clay ranges from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). Lithoclasts of clay are often found in other lithologies. Smectite, illite, palygorskite, and sepiolite comprise the clay mineral suite (Reynolds, 1962).

Quartz sand beds also occur sporadically and are generally less than 5 feet thick. They are very fine to medium grained (characteristically fine grained), poorly to moderately indurated, clayey, dolomitic and phosphatic. The sands are usually yellowish gray (5 Y 8/1) in color.

Chert is also sporadically presently in the Arcadia Formation in the updip areas (portions of Polk, Hillsborough, Manatee and Hardee Counties). In many instances the chert appears to be silicified clays and dolosilts.

Subjacent and Suprajacent Units

The Arcadia Formation overlies either the Ocala Group or the "Suwannee" Limestone in the south Florida region (Figure 8). The contact between the basal Arcadia and the Ocala Group is an easily recognized unconformity. In the north central and northeastern portions of southern Florida, where the Hawthorn Group overlies the Ocala Group (Figures 8 and 41), the Arcadia is characteristically a gray, hard, quartz sandy, phosphatic dolostone with a few siliciclastic interbeds. This is in contrast to the Ocala Group, which is a cream to white, fossiliferous, soft to hard limestone (packstone to wackestone).

Throughout most of south Florida, the Hawthorn Group overlies limestones most often referred to as the "Suwannee" Limestone (Figure 33). In much of this area the contact is recognizably unconformable. The contrast between the sandy, phosphatic, fine-grained to finely crystalline carbonates of the Arcadia and the coarser grained nonphosphatic, non-quartz-sandy limestones of the "Suwannee" Limestone allow the contact to be easily placed. However, in the downdip areas (e.g., Lee and Charlotte Counties and further south) the contact becomes more obscure. In this area the contact is placed at the base of the last occurrence of a sandy, variably phosphatic carbonate.

The limestones underlying the Arcadia are referred to as "Suwannee" limestone due to the uncertainty of the formational assignment. These sediments have characteristically been called "Suwannee" by previous workers despite the fact that they have never been accurately correlated with the typical Suwannee Limestone in northern Florida. Hunter (personal communication, 1984) believes that these carbonates are not Suwannee or the equivalent but are an unnamed limestone of Chickasawhayan Age (Late Oligocene).

Unconformably overlying the Arcadia Formation is the Peace River Formation (Figure 33). The Peace River Formation is predominantly a siliciclastic unit with varying amounts of carbonate beds. The percentage of carbonate beds is higher near the base of the Peace River, resulting in a transitional or gradational contact with the Arcadia. In some areas the contact is often marked by a phosphatic rubble zone and/or a phosphatized dolostone hardground. In the more gradational sequence the contact is placed where the carbonate beds become significantly more abundant than the siliciclastic beds.

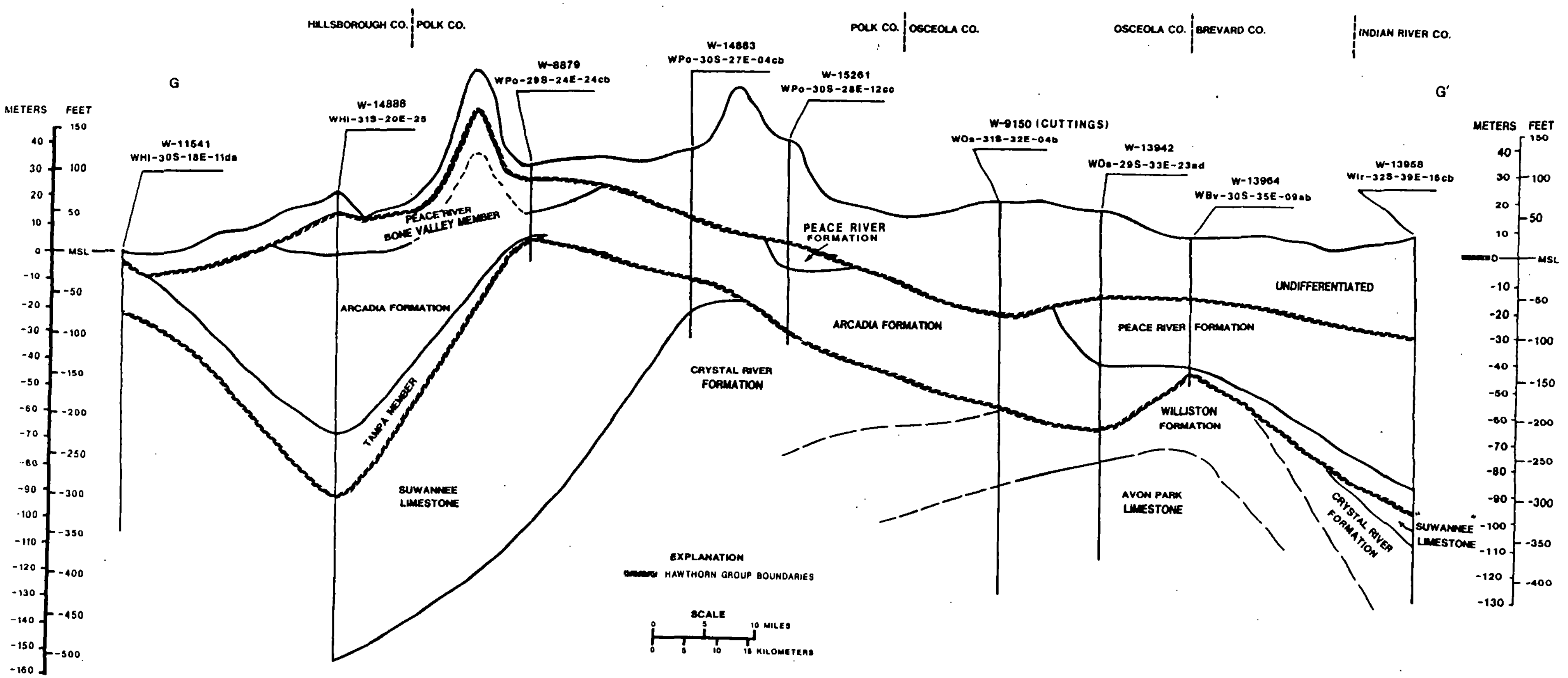


Figure 35. Cross section G-G' (see figure 3 for location).

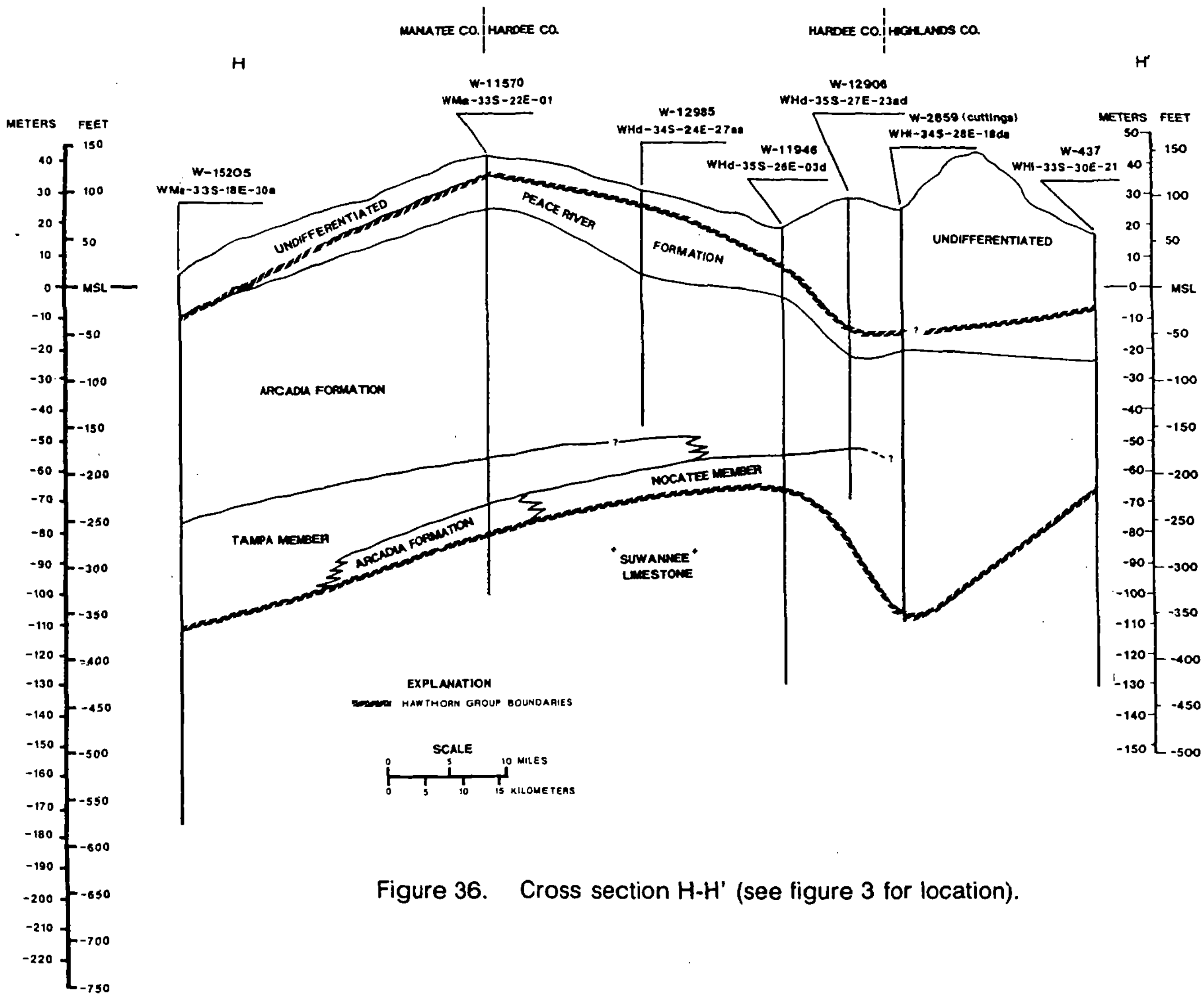


Figure 36. Cross section H-H' (see figure 3 for location).

The relationship of the subjacent and suprajacent units to the Arcadia Formation can be seen in the cross sections shown in Figures 35 through 40.

Thickness and Areal Extent

The Arcadia Formation occurs primarily as a subsurface unit throughout its extent. The top of the Arcadia Formation in cores ranges from -440 feet MSL (134 meters) in W-15493 Monroe County to greater than + 100 feet MSL (30 meters) in several cores in Polk County (Figure 41). Data obtained from well cuttings in areas lacking core data indicated that the top of the Arcadia may be greater than -750 feet MSL (229 meters) in Palm Beach and Martin Counties (Figure 41).

The Arcadia Formation appears to be absent from the southern nose of the Ocala Platform, the Sanford High and part of the Brevard Platform (Figures 41 and 42). It increases in thickness away from these features, reaching a maximum of 593 feet (181 meters) in a core in Charlotte County (Southeast Florida Water Management District R.O.M.P. 3-3) and more than 650 feet (198 meters) in a well in southern Dade

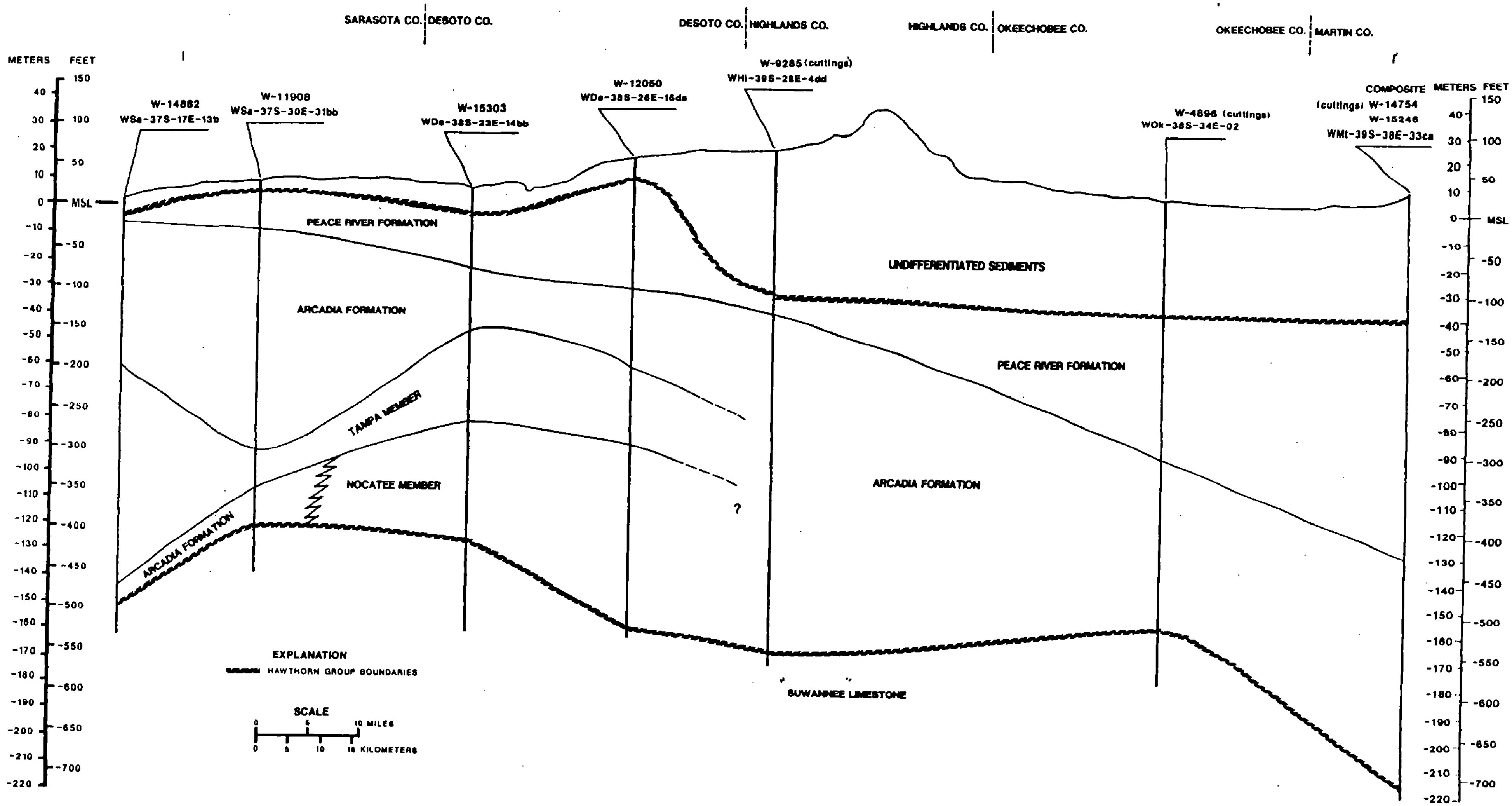


Figure 37. Cross section I-I' (see figure 3 for location).

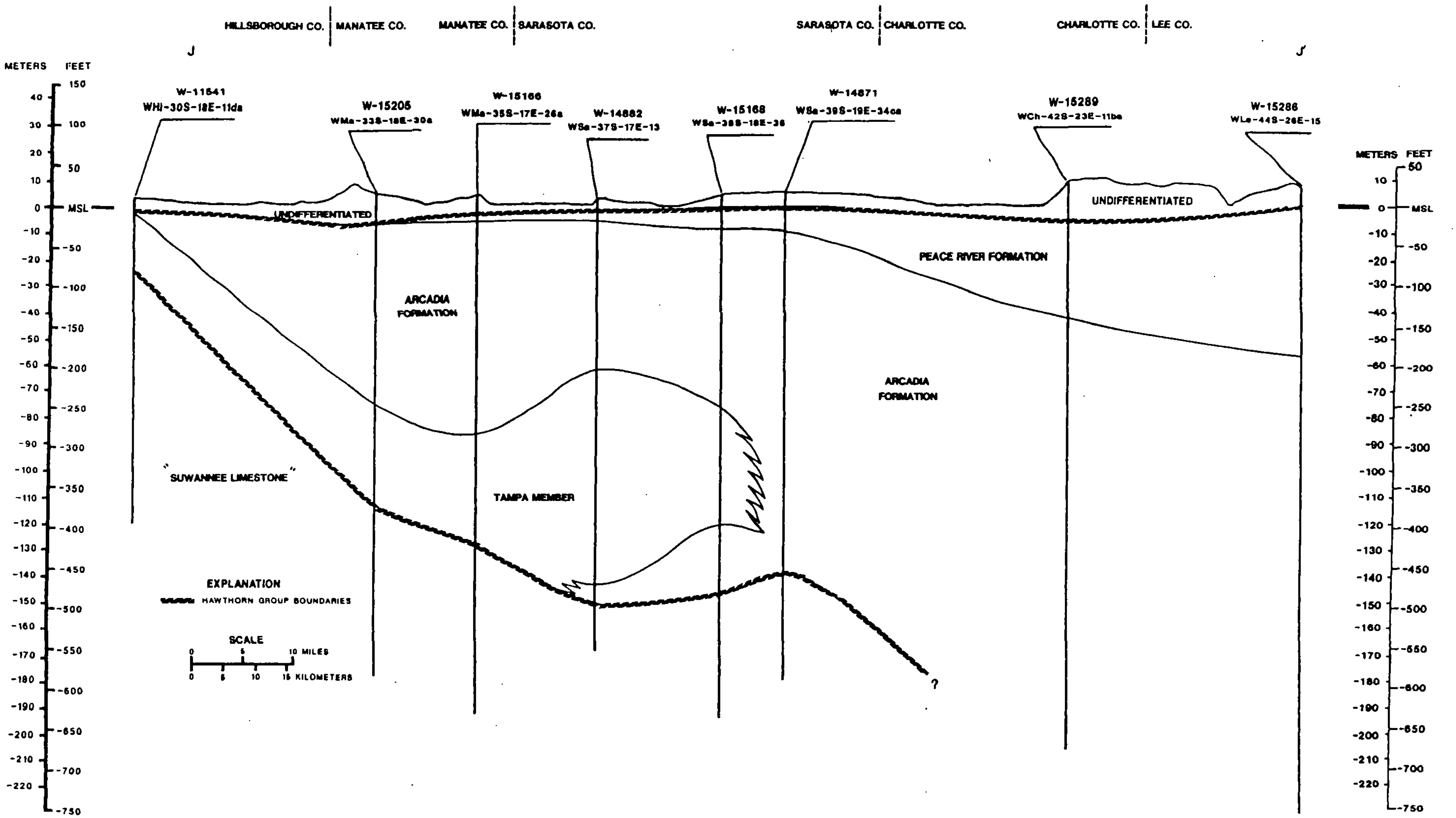


Figure 38. Cross section J-J' (see figure 3 for location).

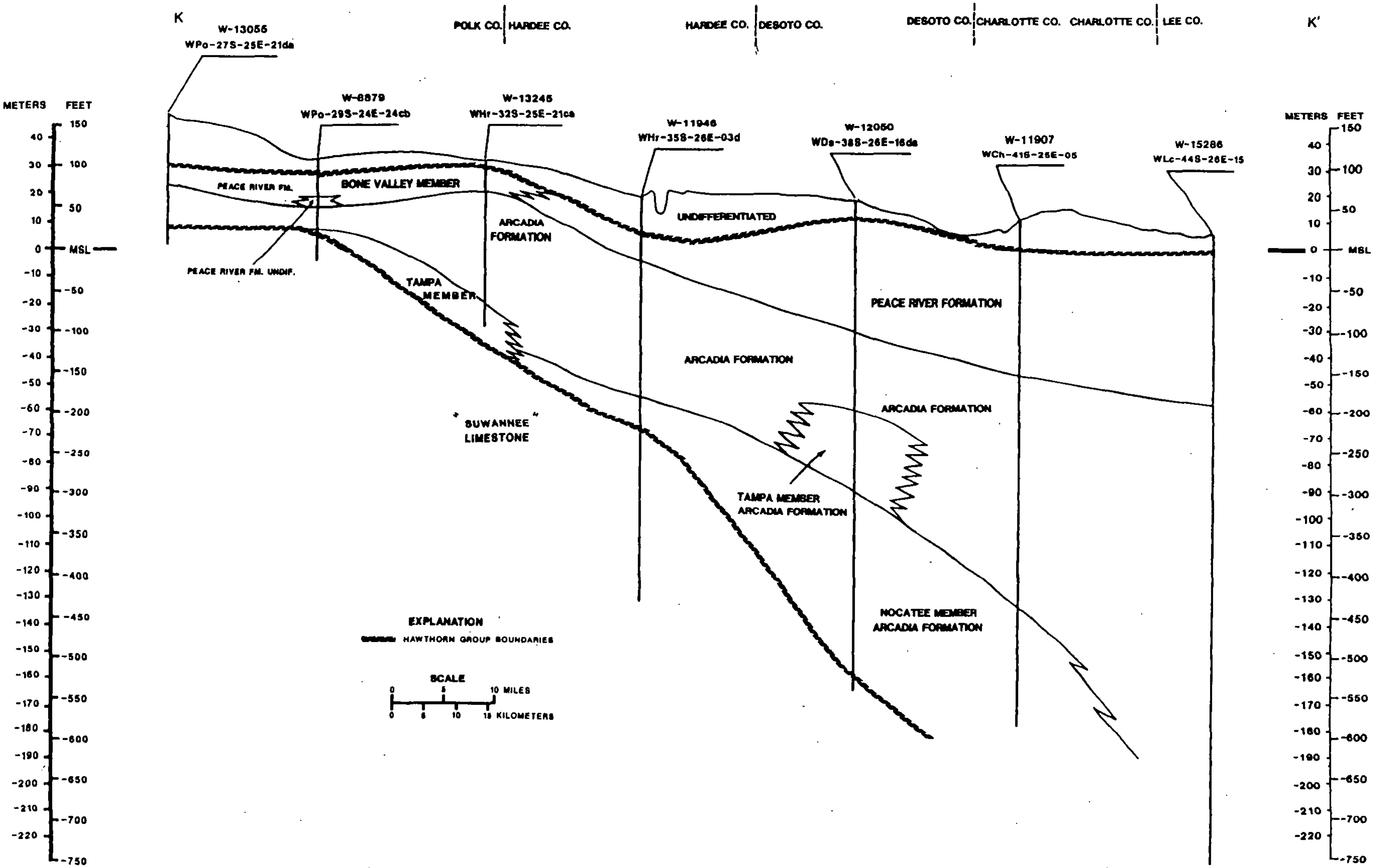


Figure 39. Cross section K-K' (see figure 3 for location).

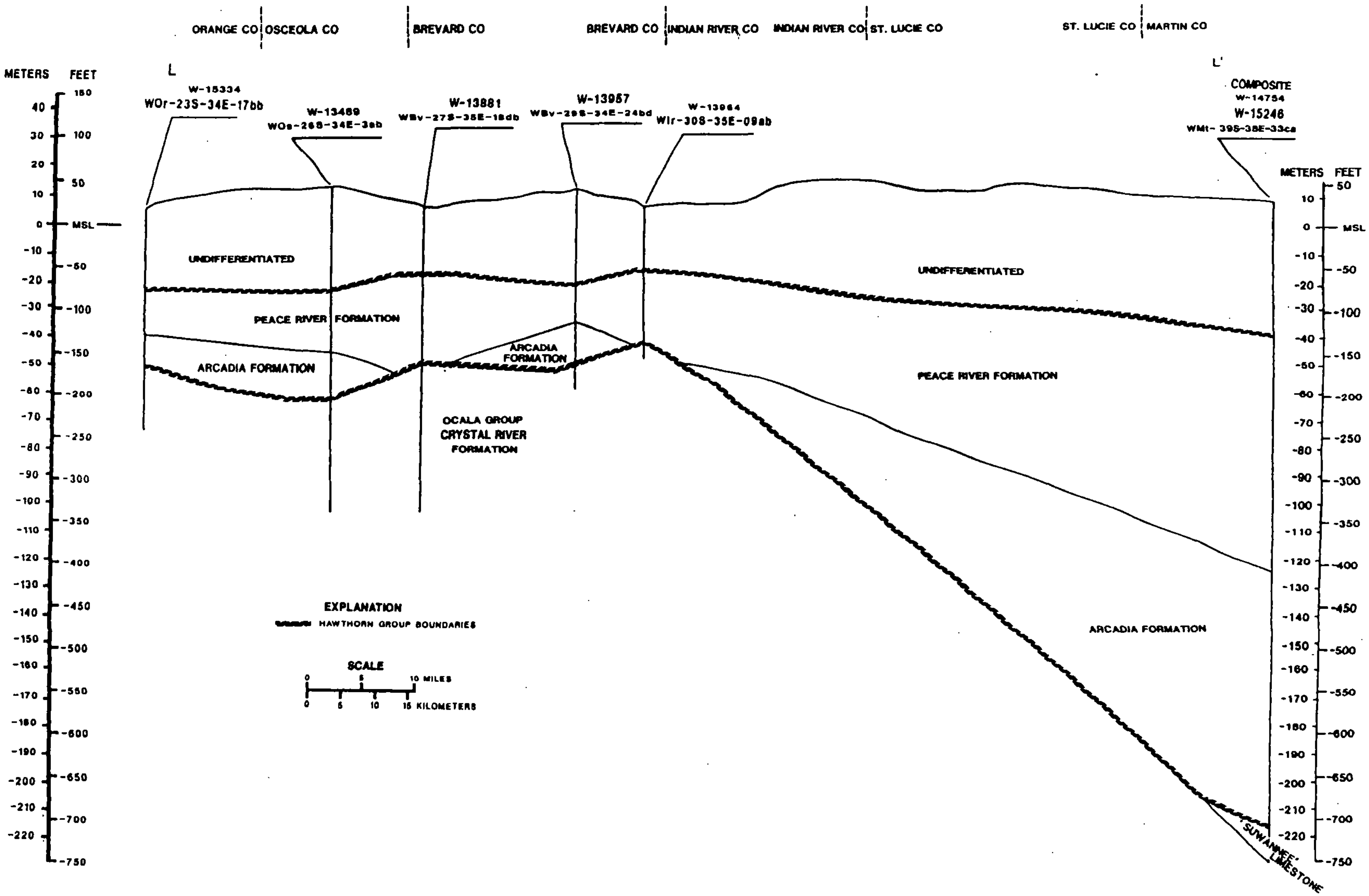


Figure 40. Cross section L-L' (see figure 3 for location).

County (Figure 42).

The dip of the Arcadia Formation exhibits some variability in the northern portion of the south Florida area (Figure 41). This is primarily due to the occurrence of the Ocala Platform, Osceola Low, Sanford High and the Brevard Platform (Figure 4). In general, however, the dip is to the southeast at approximately 5 feet per mile (0.9 meters per kilometer).

The basal unit of the Hawthorn Group is present throughout the south Florida area. It is apparently absent from the southern flanks of the Ocala Platform and the Sanford High and from part of the Brevard Platform. This is at least partially due to erosion prior to Peace River deposition. The Arcadia Formation is not identifiable in the area between the Ocala Platform and the Sanford High. A carbonate unit is present in this area, but it has characteristics attributable to both the Arcadia and Penney Farms Formations. Until further research can be conducted, the Hawthorn Group remains undifferentiated in this area.

In the southern portion of south Florida, the Arcadia contains an increasing percentage of very moldic (mollusk shell molds) limestones and the entire carbonate section becomes less phosphatic to the south.

The Arcadia Formation was tentatively identified in the Port Bougainville core, W-15493, Monroe County (upper Keys). The transition from the typical Arcadia in southwest Florida to that in the upper Keys is difficult to ascertain due to the nearly complete lack of core data and paucity of well cuttings in the area. Further research, when the data become available, will be necessary to clarify these questions.

Age and Correlation

The sediments of the Arcadia Formation have yielded few dateable fossil assemblages. Diagenesis of the original carbonate sediments has destroyed most fossil material leaving only casts and molds. From mollusk samples collected by Hunter (personal communication, 1984) in portions of southwest Florida, the upper part of the Arcadia correlates with part of the Marks Head Formation of north Florida and Georgia and the Torreya Formation of the Florida panhandle. This suggests that the upper Arcadia is no younger than mid-Burdigalian (late Eary Miocene) (Figure 19). The lower Arcadia seems to be equivalent to the Penney Farms Formation and part of the Parachucla Formation Georgia (Figure 19) (Huddlestun, personal communications, 1983; Hunter, personal communication, 1984). The base of the Arcadia may be as old as early to middle Aquitanian (early Early Miocene) (Figure 19).

Discussion

The Arcadia Formation as described in this report is important from both a hydrologic and economic viewpoint. Hydrologically, it incorporates several aquifers and confining units identified within the Hawthorn Group. Economically, the carbonates of the Arcadia form the base of the mineable phosphorite throughout much of the Central Florida Phosphate District. The Arcadia Formation as used here provide a coherent picture of the early part of the Miocene in southern Florida.

TAMPA MEMBER OF THE ARCADIA FORMATION

Definition and Type Section

The Tampa Member of the Arcadia Formation represents a lithostratigraphic change in status from formation to member. The Tampa has long been a problematic unit due to facies changes and apparent gradational contacts with overlying and underlying units. The change from formation to member is necessary due to the limited areal extent of the Tampa and its lithologic similarities and relationships with the remainder of the Arcadia Formation of the Hawthorn Group. The Tampa Member is predominantly a subsurface unit throughout its extent cropping out only in the Tampa area.

King (1979) and King and Wright (1979) thoroughly discussed the Tampa Member (their Tampa Formation) and its type locality. They designated Ballast Point core W-11541, Hillsborough County as the prin-

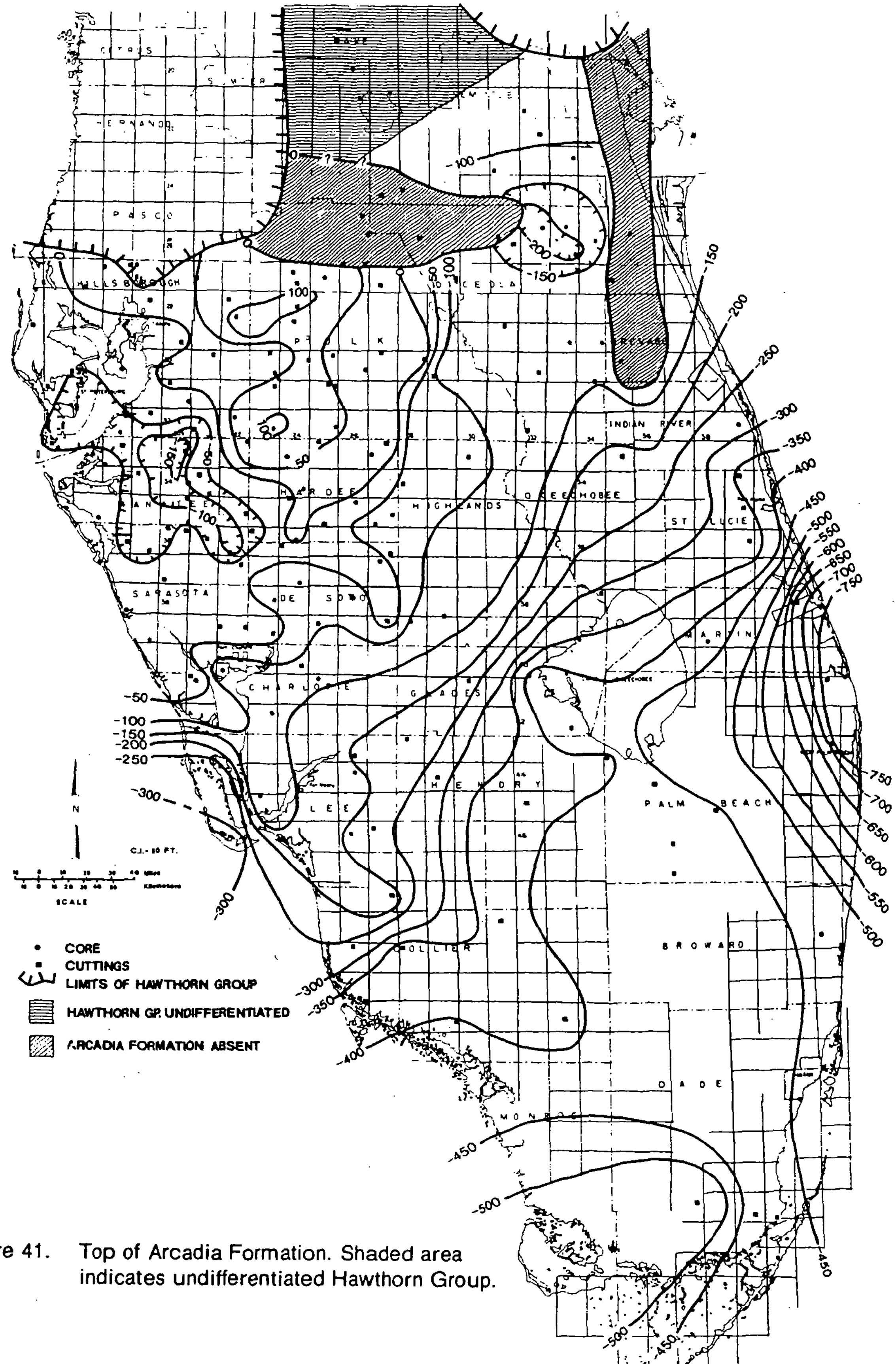


Figure 41. Top of Arcadia Formation. Shaded area indicates undifferentiated Hawthorn Group.

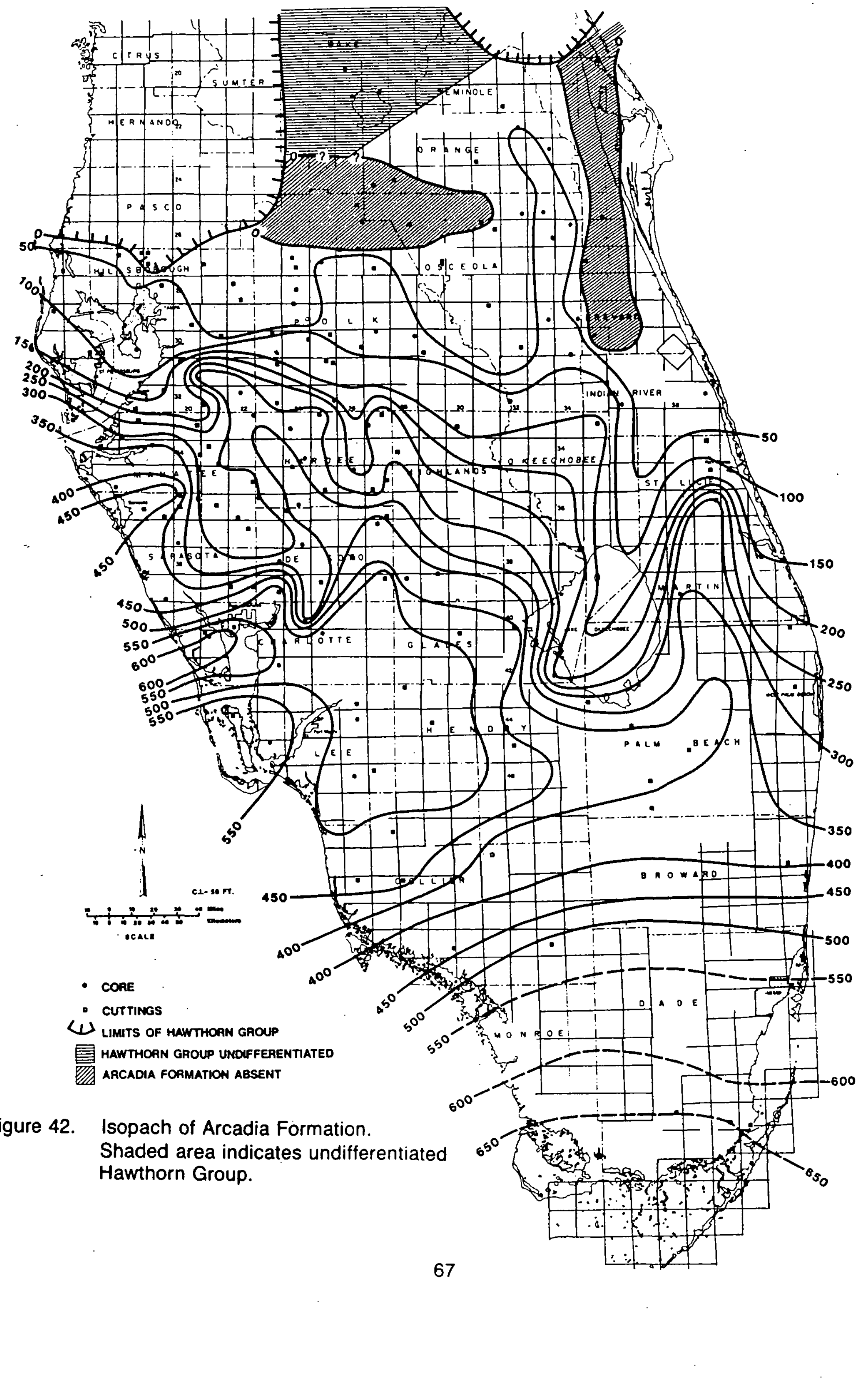


Figure 42. Isopach of Arcadia Formation. Shaded area indicates undifferentiated Hawthorn Group.

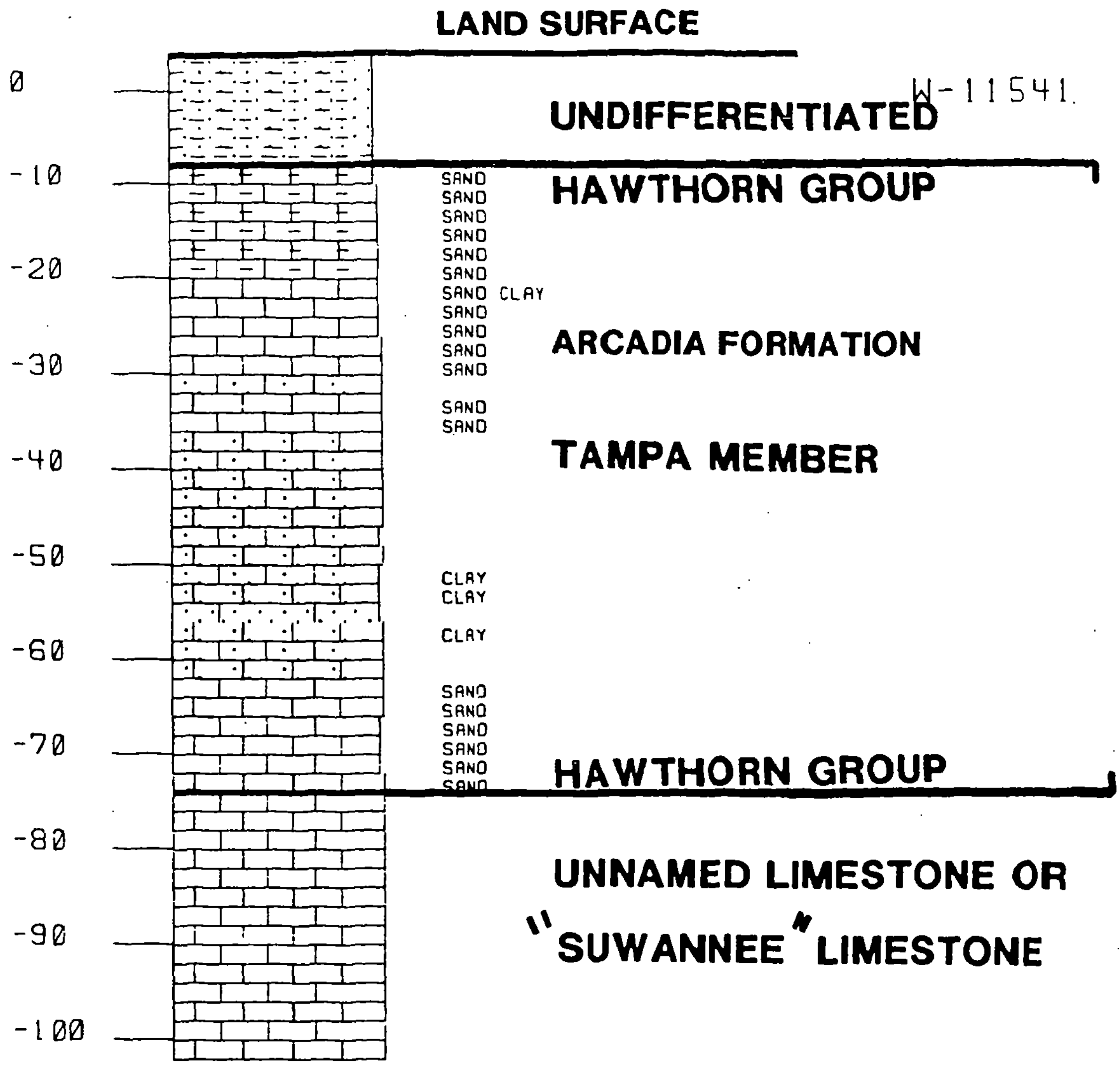


Figure 43. Reference core for the Tampa Member of the Arcadia Formation, Ballast Point #1, W-11541, Hillsborough County (Lithologic legend Appendix A).

cipal reference core (SE¼, NW¼, of Section 11, Township 30S, Range 18E). The Tampa Member occurs from -9 feet (-2.7 meters) MSL to -74 feet (-22.5 meters) MSL in this core (Figure 43). They also referred to two other cores (Duette #1, W-11570, Manatee County and Brandon #1, W-11531, Hillsborough County) as reference cores. This author also recognizes core W-15166 (Bradenton R.O.M.P. TR 7-1, W¼ of Section 26, Township 35S, Range 17E, Manatee County) as an excellent reference section for the Tampa Member. W-15166 contains the Tampa Member from -285 feet (-87 meters) MSL to -423 feet (-129 meters) MSL (Figure 44).

The classical type area of the Tampa Member lies around Tampa Bay at Ballast Point and Six Mile Creek (Dall and Harris, 1892). Unfortunately the type exposures do not completely or accurately represent the Tampa as it occurs in the subsurface. As a result the Tampa Member discussed in this paper as a formal member of the Arcadia Formation of the Hawthorn Group is described from the previously mentioned reference cores.

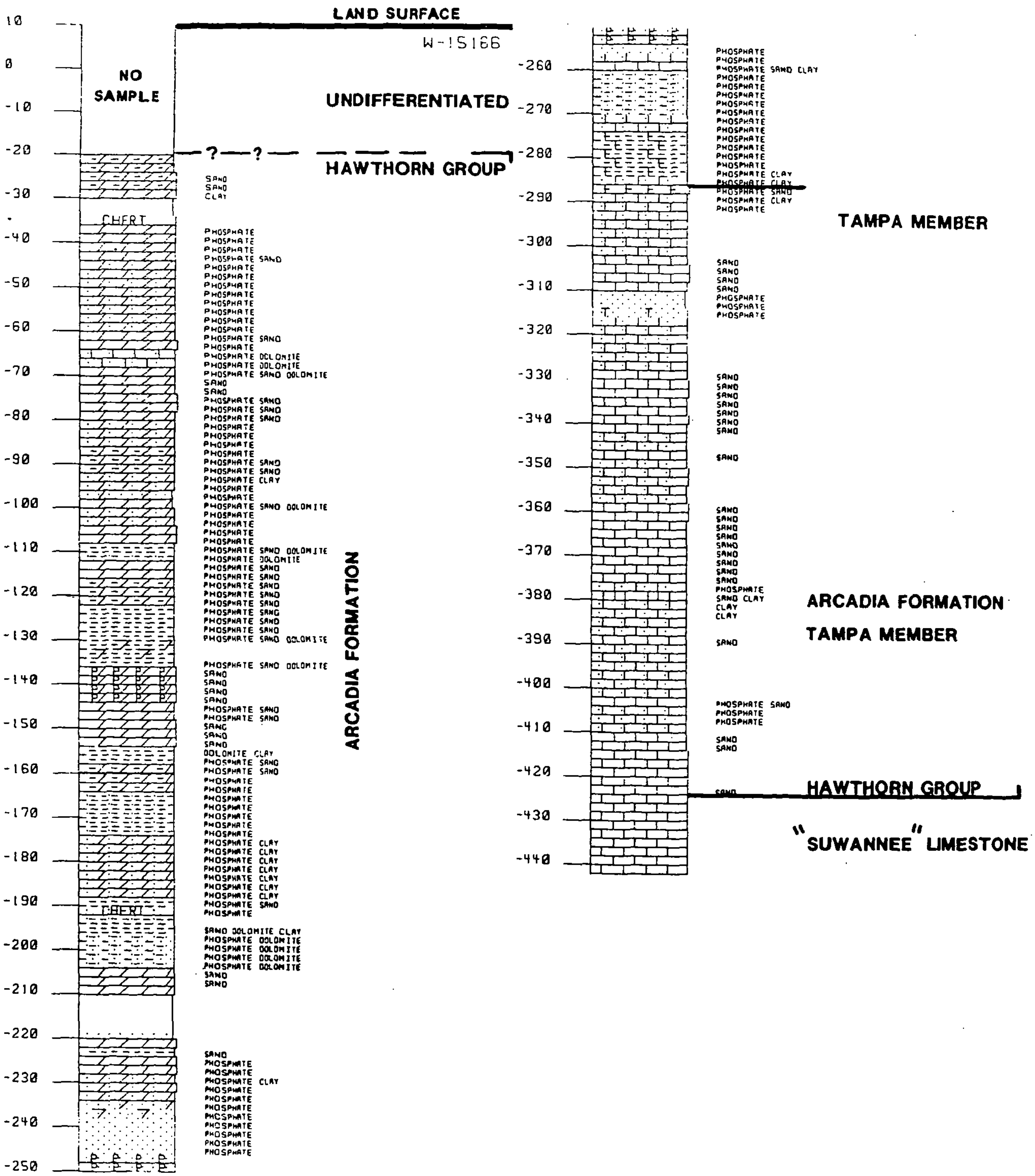


Figure 44. Reference core for the Tampa Member of the Arcadia Formation, R.O.M.P. 7-1, W-15166, Manatee County (Lithologic legend Appendix A).

Lithology

The Tampa Member consists predominantly of limestone with subordinate dolostone, sands, and clays. The lithology of the Tampa is very similiar to the limestone portion of the Arcadia Formation with the exception of its phosphate content which is almost always noticeably less than in the Arcadia. Phosphate grains generally are present in the Tampa in amounts less than 3 percent although beds containing greater percentages do occur, particularly near the facies change limits of the member.

Lithologically, the limestones are variably quartz sandy and clayey with minor to no phosphate. Fossil molds are often present and include mollusks, foraminifera and algae. Colors range from white (N 9) to yellowish gray (5 Y 8/1). The limestones range from mudstones to packstones but are most often wackestones. The dolostones are variably quartz sandy and clayey with minor to no phosphate. They are typically microcrystalline to very fine grained and range in color from pinkish gray (5 YR 8/1) to light olive gray (5 Y 6/1). The dolostones often contain fossil molds similar to those in the limestones.

Sand and clay beds occur sporadically within the Tampa Member. Lithologically, they are identical to those described for the Arcadia Formation except for the phosphate content which is significantly lower in the Tampa Member.

Siliceous beds are often present in the more updip portions of the Tampa. In the type area near Tampa Bay the unit is well known for silicified corals, siliceous pseudomorphs of many different fossils and chert boulders.

Subjacent and Suprajacent Units

The Tampa Member overlies the "Suwannee" Limestone in areas where the Nocatee Member is not present and the Tampa Member forms the base of the Arcadia. The boundary often appears gradational as discussed by King (1979) and King and Wright (1979). Figure 19 indicates an unconformable time relationship with the "Suwannee" Limestone which often is not apparent lithologically. This indicates a probable reworking of underlying materials into the Tampa Member obscuring the unconformity.

The Tampa Member overlies the Nocatee Member in the area where both are present (Figure 33). The contact appears conformable and is easily recognized. In a few areas where the Nocatee is absent, the Tampa may overlie undifferentiated Arcadia Formation sediments. The Tampa Member may be both overlain and underlain by undifferentiated Arcadia.

The Tampa Member is overlain throughout most of its extent by carbonates of the undifferentiated Arcadia Formation. The contact often appears gradational over one or two feet. An increase in phosphate grain content is the dominant factor in defining the lithologic break. In updip areas the Tampa may be overlain by siliciclastic sediments of the Peace River Formation. Further updip it may be exposed at the surface or covered by a thin veneer of unconsolidated sands and clays which may represent residuum of the Hawthorn sediments. Figure 35 through 39 show the relationship of the Tampa Member to the overlying and underlying units.

Thickness and Areal Extent

The Tampa Member is quite variable in thickness throughout its extent. It thins updip to its northern limit where it is absent due to erosion and possibly nondeposition. The thickest section of Tampa encountered is in W-14882 in Sarasota County where 270 feet (82 meters) of section are assigned to this member (Figure 45). More typically an average thickness is approximately 100 feet (30.5 meters).

The top of the Tampa Member (Figure 46) ranges in elevation from as high as +75 feet (23 meters) MSL in northeastern Hillsborough County to -323 feet (-98.5 meters) MSL in northern Sarasota County. The lowest elevation for the top of the unit occurs in a rather large depression that encompasses part of northern Sarasota County and southern Manatee County.

The Tampa dips towards the south in the northern half of the area of occurrence (Figure 46). Dip direction in the southern half is more to the southwest and west. Dip angle varies from place to place but the

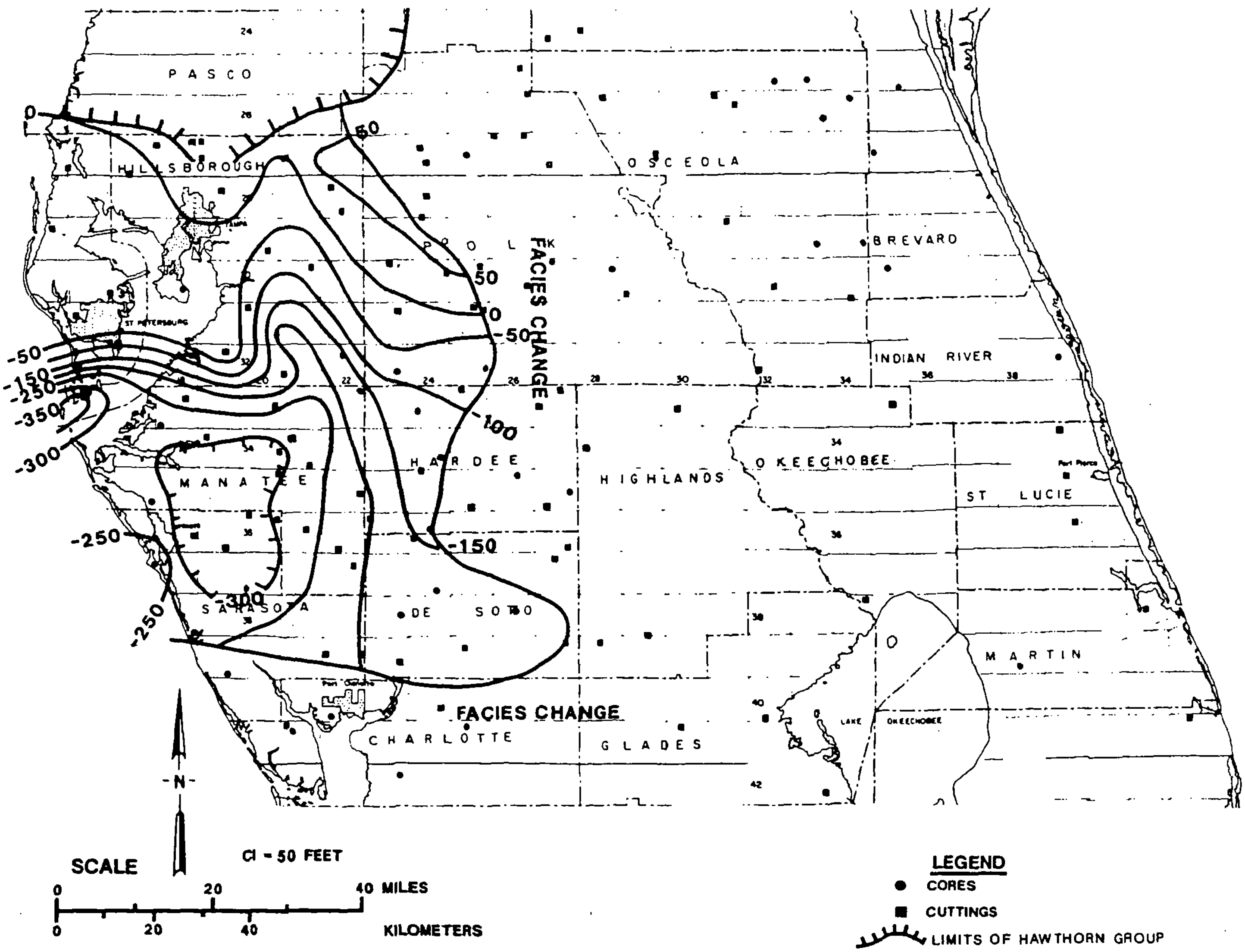


Figure 45. Top of Tampa Member.

average from highest to lowest point is approximately 8 feet per mile (1.5 meters per kilometer). The dip appears steeper in the northern and central area (Figure 46).

Figures 45 and 46 show the area of occurrence for the Tampa Member. North of this area, the Tampa has been removed by erosion and only a few, isolated, erosional remnants are present. In some areas its absence may be due to nondeposition. East and south of the area of occurrence, the Tampa grades laterally into the undifferentiated Arcadia Formation. It is important to note that relatively thin beds of Tampa lithology occur within the Arcadia Formation outside the area in which Tampa is mapped. These beds often occur sporadically throughout the lower Arcadia but are not thick enough and are too complexly interbedded with Arcadia lithologies to be mapped as Tampa Member. Characteristically, the Tampa is recognized when there are few beds of Arcadia lithologies interbedded with Tampa lithologies and the sequence of Tampa lithologies is sufficiently thick. Further data may permit more accurate definition of the limits of the Tampa Member.

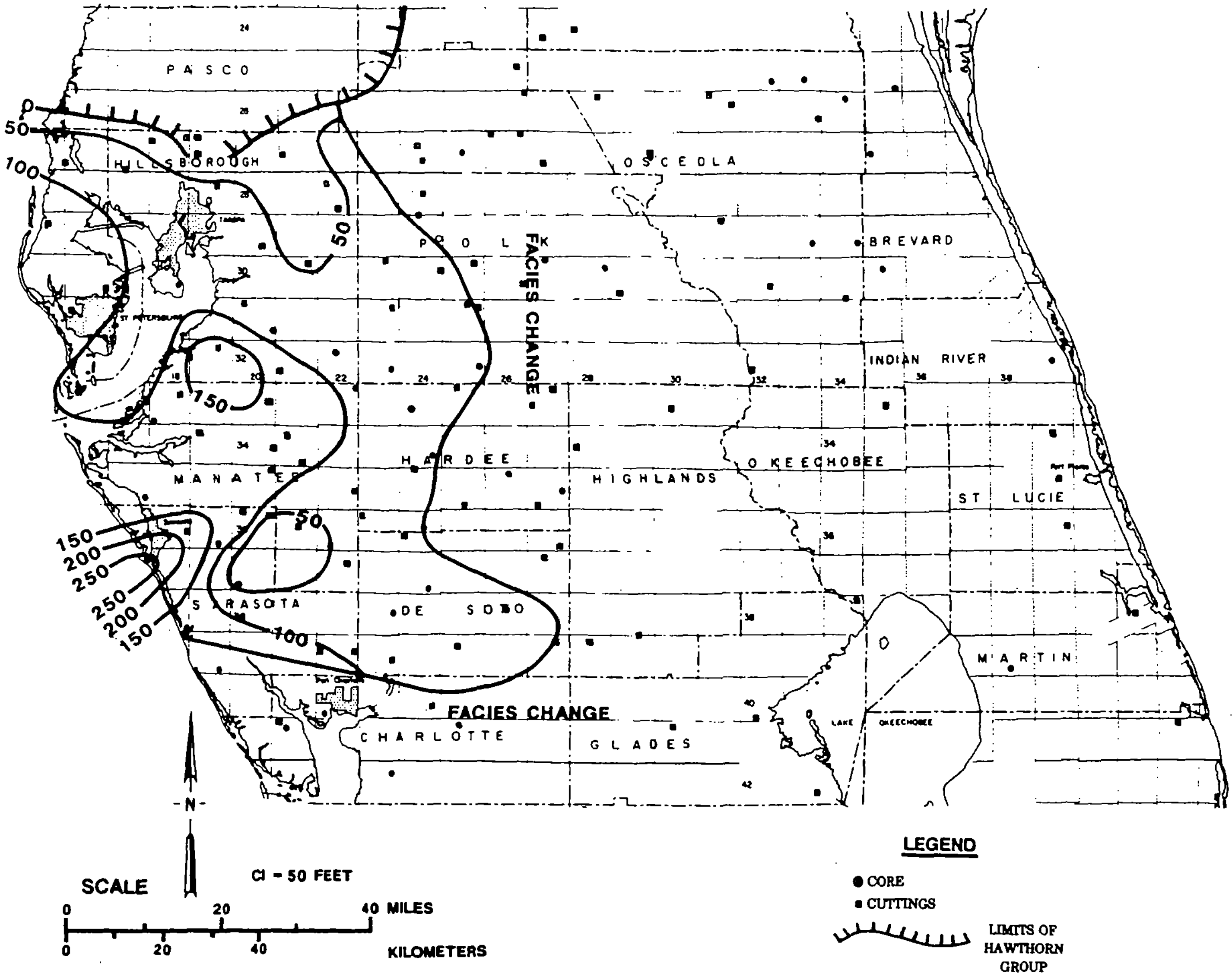


Figure 46. Isopach of Tampa Member.

Age and Correlation

The Tampa Member is characteristically variably fossiliferous. Mollusks are most common with corals and foraminifera also present. Despite the presence of these fossils, no age diagnostic species have yet been recognized.

MacNeil (1944) suggested the correlation of the Tampa with the Paynes Hammock Formation of Mississippi based on the mollusk fauna present in each. Poag (1972) dated the Paynes Hammock Formation using planktic foraminifera and suggested a Late Oligocene age (N2-N3 of Blow, 1969). Huddlestun (personal communication, 1984) indicates that the Tampa Member equates with part of the Parachucla Formation in Georgia and straddles the boundary between the Oligocene and Miocene. Hunter (personal communication, 1984) agrees with Huddlestun and correlates the Tampa with part of the lower Parachucla. Hunter also feels that much of what is incorporated into the Tampa Member in this

paper is older than the original type Tampa (Silex Beds) at Ballast Point and Six Mile Creek. The Tampa is also correlated with part of the Penney Farms Formation in north Florida (Figure 19).

Discussion

The introduction of the Tampa as a member of the Arcadia Formation represents a status reduction from formation. The reduction is necessary due to the limited areal extent of the Tampa and its interfingering, gradational nature with part of the Arcadia Formation. The historical significance of the Tampa and its widespread use suggest a retention of the name. This revision of the Tampa hopefully will provide an understandable, useable unit of local extent and places it within a regional perspective.

NOCATEE MEMBER OF THE ARCADIA FORMATION

Definition and Type Section

The Nocatee Member is a new name introduced here for sediments at the base of the Arcadia Formation in parts of southwest Florida. Previously, this interval had been informally called the "sand and clay unit" of the Tampa Limestone by Wilson (1977). This unit is recognized only in the subsurface. The Nocatee Member is named for the town of Nocatee in central DeSoto County, Florida. The type core is W-12050, Hogan #1, located in the SE ¼, NW ¼, Section 16, Township 38S, Range 26E, with a surface elevation of 62 feet (19 meters). The type Nocatee occurs between -294 feet (-89.5 meters) MSL and -520 feet (-158.5 meters) MSL (Figure 47). The type core was drilled by the Florida Geological Survey.

Lithology

The Nocatee Member is a complexly interbedded sequence of quartz sands, clays, and carbonates, all containing variable percentages of phosphate. Figure 47 shows the nature of the Nocatee in W-12050 in central Desoto County.

The Nocatee is a predominantly siliciclastic unit in the type core (W-12050). This is a noticeable change from the remainder of the Arcadia Formation including the Tampa Member, which are predominantly carbonates with variable percentages of included siliciclastics. The quartz sands in the Nocatee are typically fine to coarse grained, occasionally silty, clayey and calcareous to dolomitic. The quartz sands range in color from white (N 9) to light olive gray (5 Y 6/1). Phosphate grain content is quite variable. In the type core, phosphate grain content is generally low (1-3 percent) with scattered beds with greater concentrations (up to 10 percent). However, in the Nocatee Member in other cores (W-15303, for example, Figure 48), phosphate grains are more common, averaging about 7-8 percent.

Clay beds are quite common in the Nocatee Member and are variably quartz sandy, silty, phosphatic, and calcareous to dolomitic. The colors characteristically range from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1) and olive gray (5 Y 4/1). Limited x-ray data suggest that the characteristic clay mineral present is smectite, with palygorskite common. Illite and sepiolite are also present. Further analyses are needed to confirm the identifications and relative abundances of these clay minerals within the Nocatee Member.

Limestone and dolostone are both present in this member. The ratio of limestone to dolostone is variable, as can be seen by comparing W-12050 (Figure 47) with W-15303 (Figure 48). The limestones are generally fine grained, soft to hard, quartz sandy and phosphatic. The percentage of clay present is quite variable and grades into the clay lithology. Colors of the limestone vary from white (N 9) to yellowish gray (5 Y 8/1) and light olive gray (5 Y 6/1), generally in response to clay content. The limestones are usually wackestones with varying degrees of recrystallization and cementation.

The dolostones are quartz sandy, phosphatic, soft to hard, and micro- to very finely crystalline. Variable amounts of clay are present. Colors range from yellowish gray (5 Y 8/1) to light gray (N 7), light olive gray (5 Y 6/1) and grayish brown (5 Y 3/2).

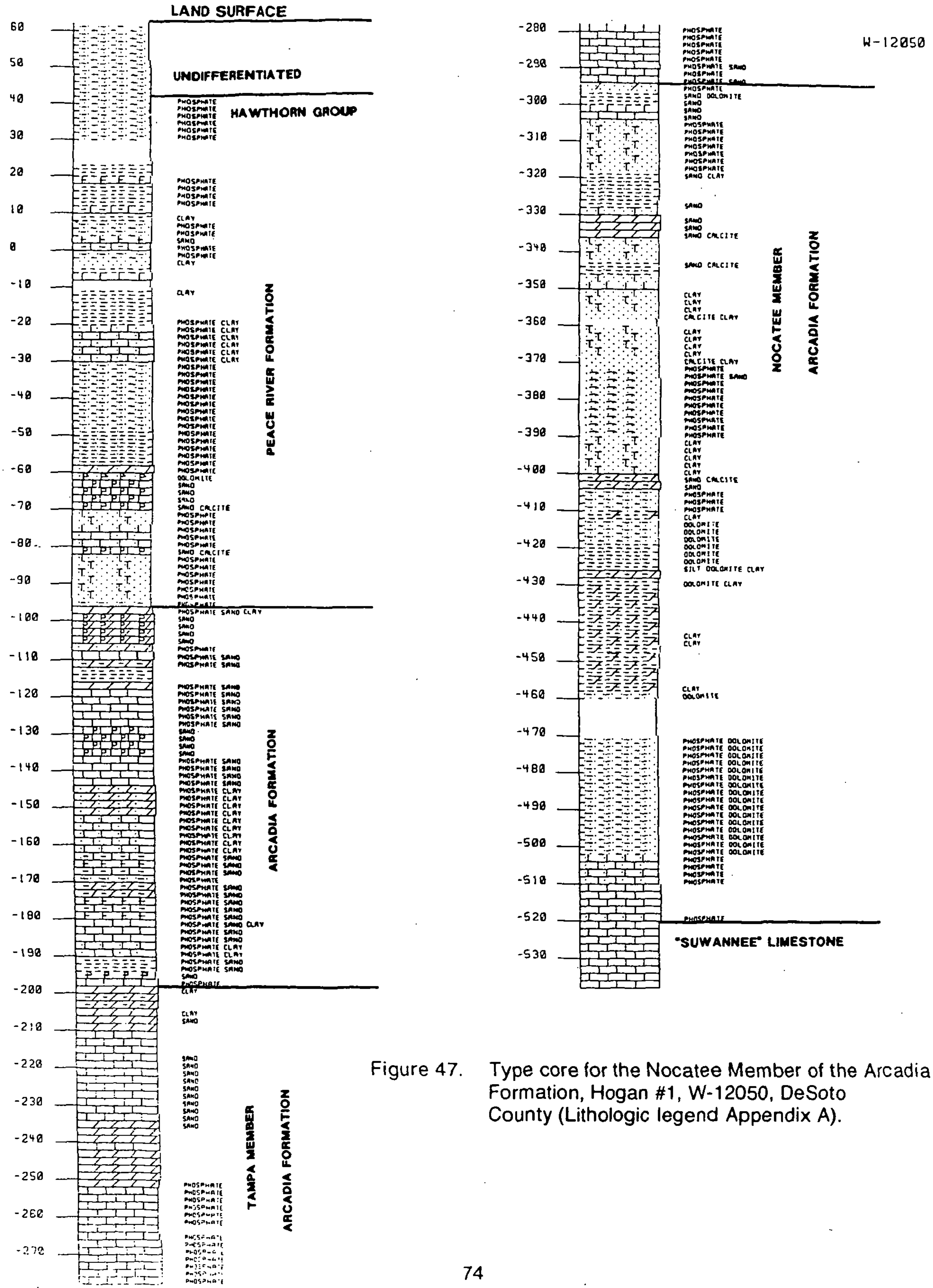


Figure 47. Type core for the Nocatee Member of the Arcadia Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

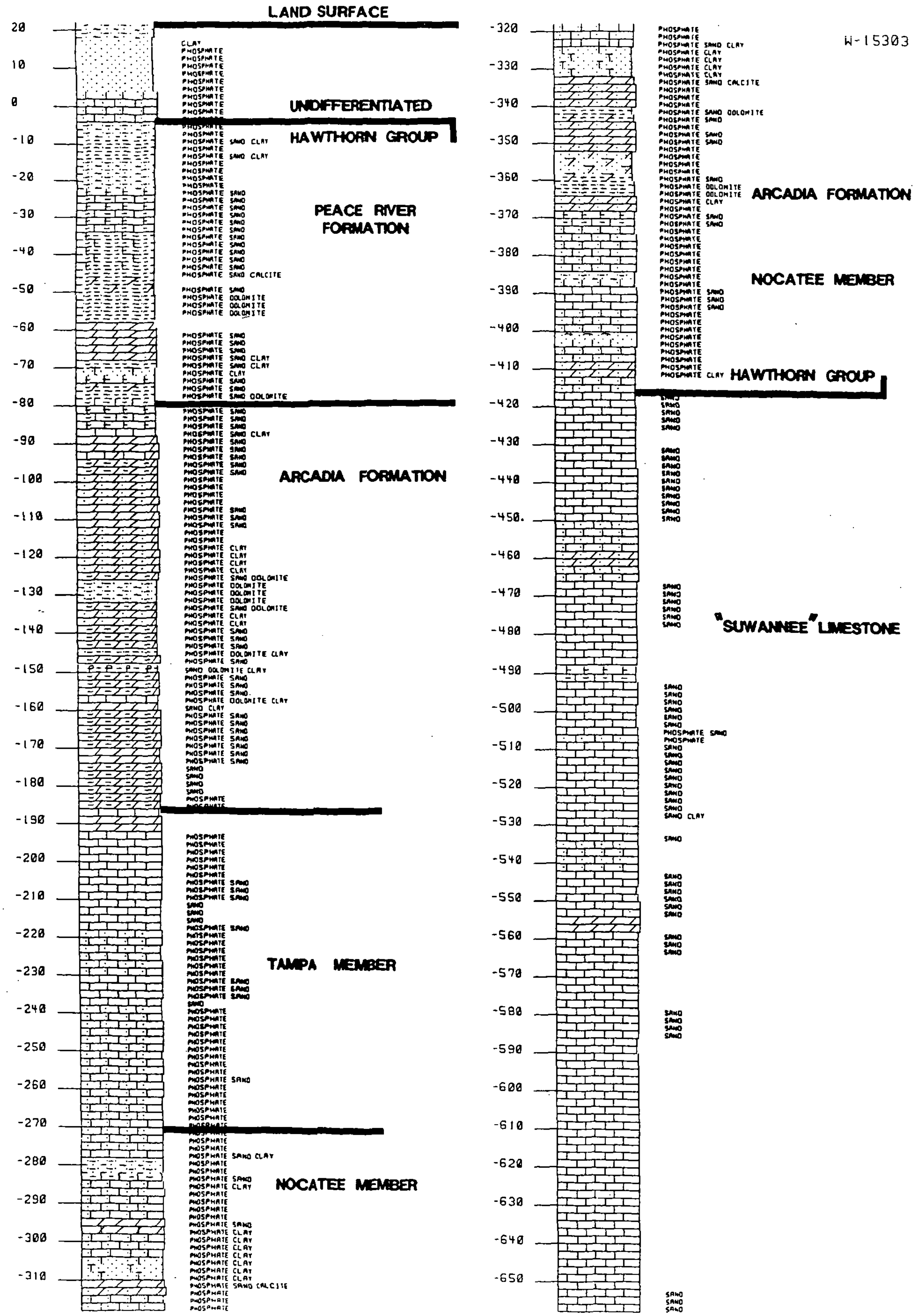


Figure 48. Reference core for the Nocatee Member of the Arcadia Formation, R.O.M.P. 17, W-15303, DeSoto County (Lithologic legend Appendix A).

Fossils are often present in the Nocatee, most often as molds. However, in some of the clay beds diatoms are present but have not been identified. Fossils present include mollusks, algae, foraminifera and corals.

Subjacent and Suprajacent Units

The Nocatee Member overlies limestones currently assigned to the "Suwannee" Limestone. The contact between the units often appears gradational from the basal, quartz-sandy, phosphatic, occasionally clayey carbonates of the Nocatee into the slightly quartz sandy, non-phosphatic limestones of the "Suwannee" (Figures 47 and 48). Occasionally, the basal Nocatee is a siliciclastic unit and it is easily differentiated from the limestones of the "Suwannee." The contact is suggested to be a disconformity based on paleontology (Huddlestun, personal communication, 1984).

The Tampa Member overlies the Nocatee throughout much of the area. The top of the Nocatee is generally placed at the top of the siliciclastic section below the Tampa (as in W-12050, Figure 47). However, occasionally there is a carbonate bed at the top of the Nocatee which contains too much phosphate to be included in the Tampa. This bed is taken as the top of the Nocatee Member. Occasionally, the Nocatee is overlain by carbonates of the undifferentiated Arcadia Formation. The relationships of the Nocatee with the subjacent and suprajacent units are shown in Figures 36, 37, and 39.

Thickness and Areal Extent

The Nocatee Member ranges in thickness up to 226 feet (70 meters) in W-12050 DeSoto County (Figure 49). Other cores in Charlotte County stopped in the Nocatee, in areas where it may be thicker. Further coring or properly sampled cuttings are needed to delinate the thickness and, possibly, the extent of the Nocatee in this area.

The top of the Nocatee ranges in depth from -81 feet (-24.5 meters) MSL in Polk County to -639 feet (-195 meters) MSL in Charlotte County (Figure 50). In general the upper surface dips to the south and southeast at an average of 7.5 feet per mile (1.7 meters per kilometer).

The Nocatee Member is of rather limited areal extent as is the Tampa Member. It has been identified in parts of Polk, Hardee, DeSoto, Charlotte, Manatee, Hillsborough, Sarasota, and possibly Highlands Counties. The lateral limits of this unit in most cases are the result of facies changes (Figures 49 and 50). In portions of the updip area, the Nocatee may be represented by a clay unit present in the Tampa, as discussed by Gilboy (1983). The extent of the Nocatee to the south and east is questionable at this time due to a lack of subsurface data (Figures 49 and 50).

Age and Correlation

The age of the Nocatee Member is based completely on its subjacent positioning to the Tampa Member and its suprajacent position to the "Suwannee" Limestone of south Florida. It is older than part of the Tampa Member, equivalent to part of the Tampa, and younger than the underlying Oligocene carbonates. This suggests an earliest Miocene age for the unit. At the present time there have been no attempts to date the unit paleontologically.

The Nocatee grades laterally westward and southward into very quartz-sandy, phosphatic carbonates of the undifferentiated Arcadia Formation. Eastward the unit grades into a more siliciclastic-rich east coast facies of the undifferentiated Arcadia. Northward, it appears that the Nocatee grades into the basal Tampa Member. The Nocatee correlates with the lower part of the type Tampa Member. It is also correlative with part of the lower Penney Farms Formation of north Florida and the lower Parachucla of southeast Georgia (Figure 19).

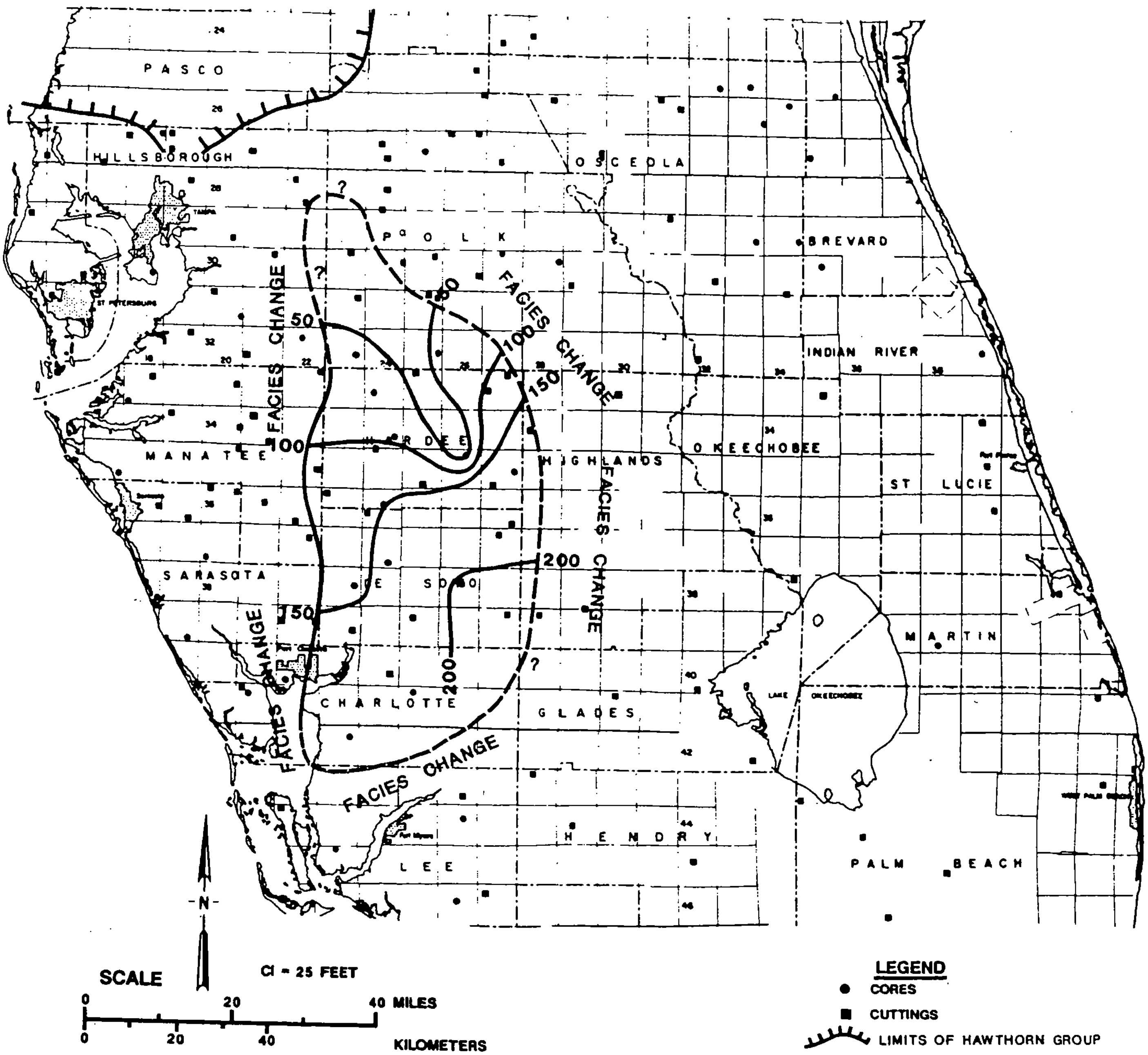


Figure 49. Isopach of Nocatee Member.

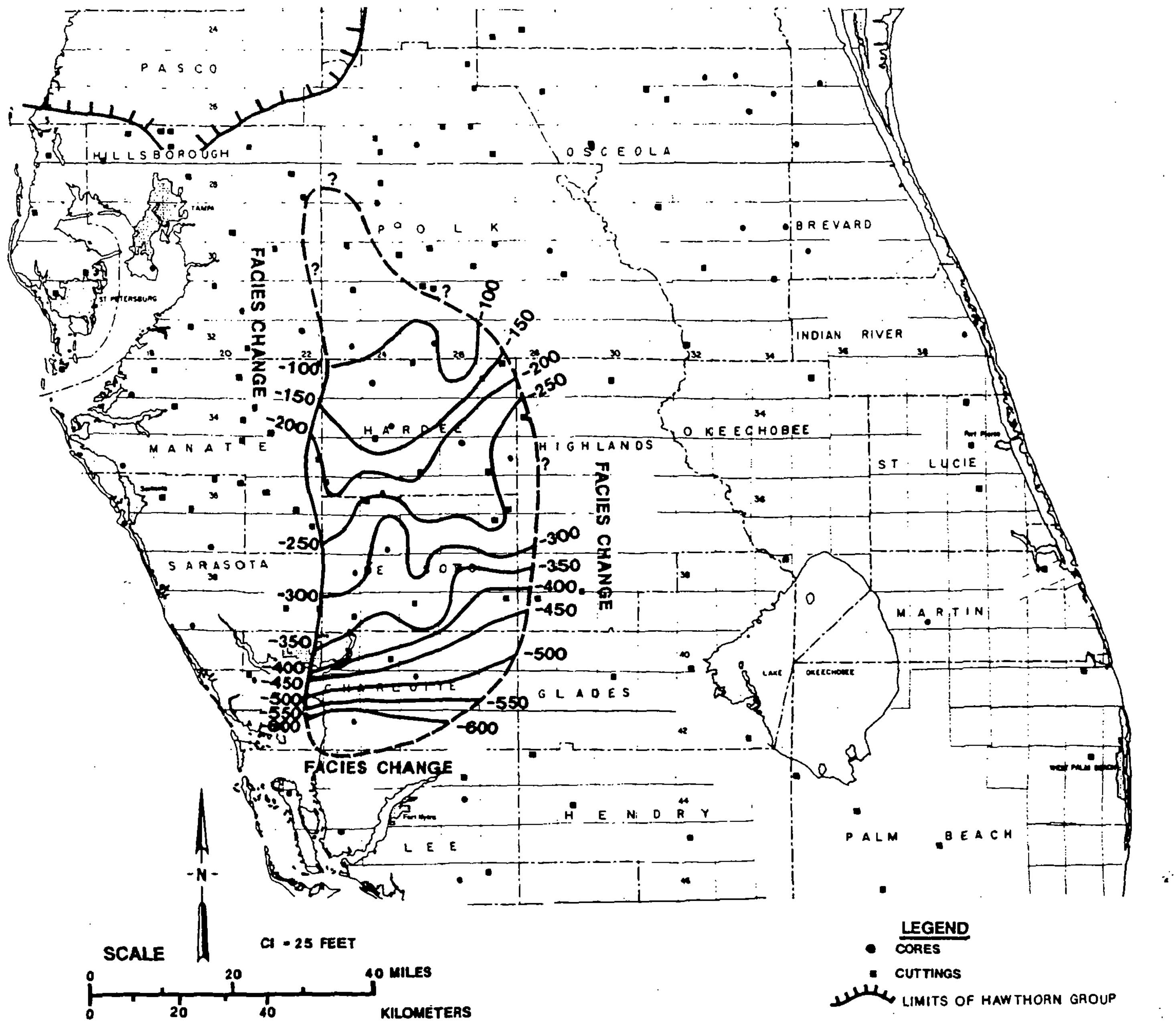


Figure 50. Top of Nocatee Member.

Discussion

The sediments of the Nocatee Member have been recognized for some time. The name "Tampa sand and clay unit" represents the first published name applied to these sediments (Wilson, 1977). Although these sediments are of limited areal extent, their distinctive lithology suggests the formal recognition of these sediments as a member of the Arcadia Formation. Outside the recognized area of occurrence equivalent carbonate sediments of the Arcadia Formation are often very sandy and may contain thin clay beds. The equivalence of the two units is recognized by the stratigraphic position.

PEACE RIVER FORMATION

Definition and Type Section

The Peace River Formation is a new formational rank name proposed for the combined upper Hawthorn siliciclastic strata and the Bone Valley Formation. The upper Hawthorn siliciclastic strata include siliciclastic beds previously placed in the Tamiami Formation (Parker, 1951) and the Murdock Station and Bayshore Clay members of the Tamiami Formation (Hunter, 1968). The formation is named for the Peace River which occurs in the vicinity of the type section in core W-12050.

The type section for the Peace River Formation is designated as core W-12050, Hogan #1, located in east central DeSoto County, Florida (SE ¼, NW ¼ Section 16, Township 38S, Range 26E) with a surface elevation of 62 feet (19 meters). The type Peace River Formation occurs between +41 feet (+12.5 meters) MSL and -97 feet (-29.5 meters) MSL (Figure 51).

W-15303, R.O.M.P. #17, is suggested as a reference section (Figure 48). R.O.M.P. #17 is located west of W-12050 in the west central part of DeSoto County (NE ¼, NE ¼ Section 14, Township 38S, Range 23E, surface elevation 22 feet (6.5 meters)). The Peace River Formation occurs between -3 feet (-1 meter) MSL and -77 feet (-23.5 meters) MSL in W-15303.

Lithology

The Peace River Formation consists of interbedded quartz sands, clays and carbonates. The siliciclastic component predominates and is the distinguishing lithologic feature of the unit. Typically the siliciclastics comprise two-thirds or more of the formation.

The quartz sands are characteristically clayey, calcareous to dolomitic, phosphatic, very fine to medium grained, and poorly consolidated. Their color ranges from light gray (N 7) and yellowish gray (5 Y 8/1) to olive gray (5 Y 4/1). The phosphate content of the sands is highly variable. In the type section (W-12050), the phosphate content is lowest in the upper part of the section and greatest near the base. The same is true for the reference section in W-15303. The phosphate occurs both as sand- and gravel-sized particles. The gravels are most abundant in the Bone Valley Member, although they may occur elsewhere in the unit.

Clay beds are quite common in the Peace River Formation. The clays are quartz sandy, silty, calcareous to dolomitic, phosphatic, and poorly to moderately indurated. Color ranges from yellowish gray (5 Y 8/1) to olive gray (5 Y 4/1). Reynolds (1962) characterized the clay minerals as consisting of smectite (montmorillonite), palygorskite (attapulgite) and sepiolite. Strom (personal communication, 1984) and Barwood (personal communication, 1984) agree that smectite and palygorskite are the dominant clay minerals in the formation.

Carbonates occur throughout the Peace River Formation. Characteristically they comprise less than 33 percent of the Peace River section. The carbonates may be either limestone or dolostone. Updip (northward), dolostone occurs more frequently. The limestones are characteristically variably sandy, clayey and phosphatic, poorly to well indurated, mudstones to wackestones. They vary in color from yellowish gray (5 Y 8/1) to white (N 9). Dolostones are micro- to very finely crystalline, variably sandy, clayey and phosphatic, and poorly to well indurated. Colors range from light gray (N 7) to yellowish gray

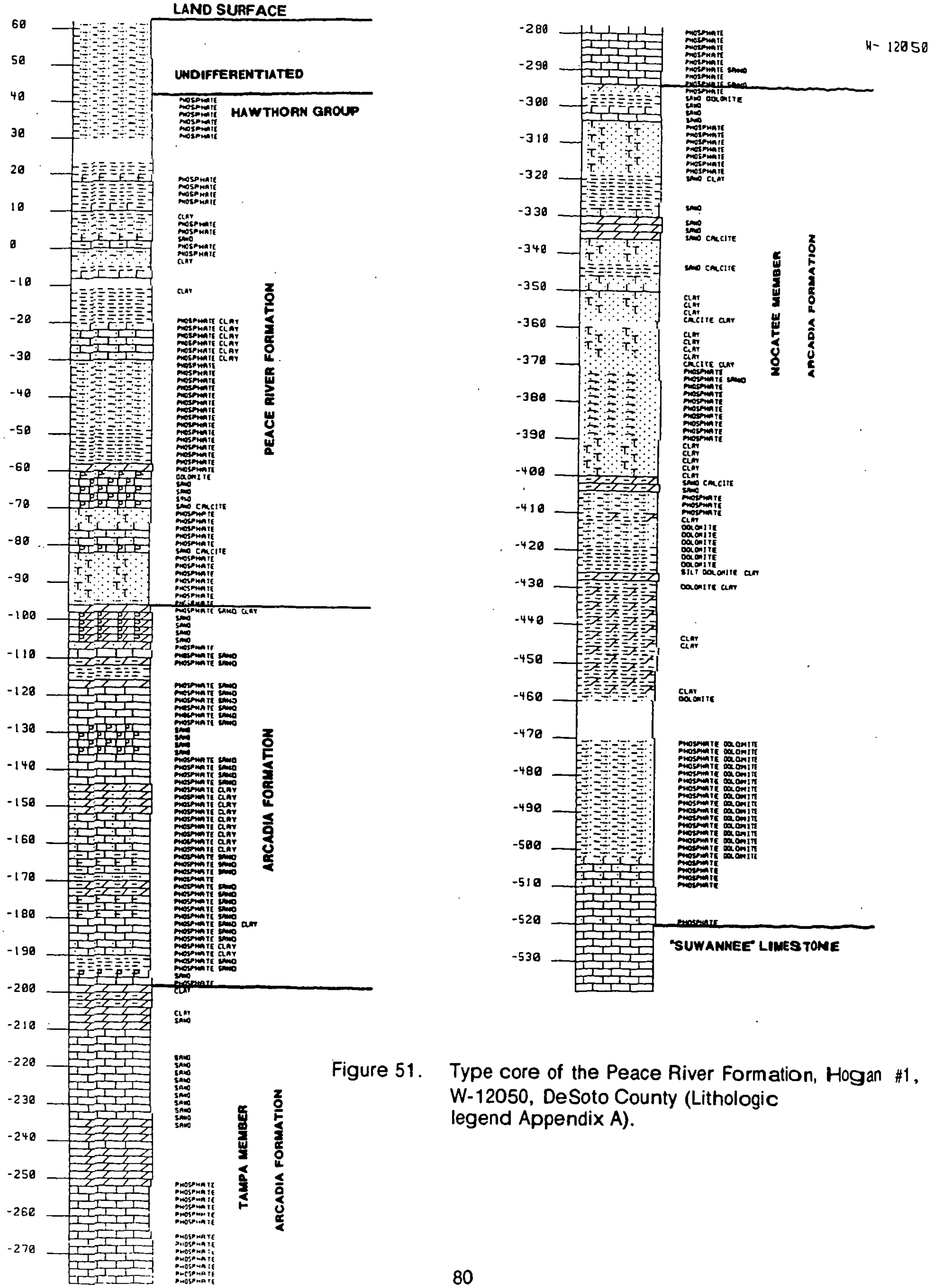


Figure 51. Type core of the Peace River Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

(5 Y 8/1). Mollusk molds are common throughout the carbonates. Occasionally dolomite occurs as a dolosilt (composed of unconsolidated, silt-sized dolomite rhombs). The dolosilts contain variable amounts of clay, are generally only slightly sandy and phosphatic, and do not contain fossil molds or fragments.

Chert occurs sporadically in the Peace River Formation. Characteristically it appears to be a replacement of the carbonates although silicified clays do occur. The cherts are opaline and are suggestive of localized "alkaline lake" deposition, as described by Upchurch, Strom and Nuckels (1982) and Strom and Upchurch (1983).

Subjacent and Suprajacent Units

The Peace River Formation disconformably overlies the Arcadia Formation throughout its extent. The contact often appears unconformable updip and conformable (gradational) downdip (Figure 35 through 40). The gradational appearance is due to the repetition of similar lithologies in both formations. When the boundary appears gradational the base of the Peace River Formation is placed where the carbonates become dominant over the siliciclastic beds (Figures 48 and 51). As was previously mentioned in the discussion of the Arcadia Formation, the contact may also be marked by a rubble zone.

The sediments overlying the Peace River Formation are assigned to several formations. In the south Florida area and the southern part of east central Florida, the limestone and sand facies of the Tamiami Formation unconformably overlie the Peace River. Sediments disconformably suprajacent to the Peace River Formation in the west central Florida area (Polk, Hillsborough, Manatee, Sarasota, and Charlotte Counties) and parts of east central Florida are generally unnamed, nonphosphatic sands (often surficial) and unnamed fossiliferous sands and shell beds. The contact with the surficial sands is often obscure due to leaching of the phosphate and clays in the upper portion of the Peace River Formation. In the central and south central section, unfossiliferous non-phosphatic to very slightly phosphatic sands overlie the Peace River. These sands have been called "Citronelle" Formation (Cooke and Mossom, 1929; Cooke, 1945) and "Fort Preston" Formation (Puri and Vernon, 1964). In Georgia, these sands are currently assigned to the Cypresshead Formation by Huddlestun (personal communication, 1984). These sediments are assigned here, for convenience, to the post-Hawthorn sediments.

Problems in identifying the upper limits of the Peace River arise in areas of extensive reworking of the sediments. In such a case the sediment may be completely reworked and the resultant lithology only slightly different than the unreworked sediments. When this occurs minor changes in lithology such as an increase in shell material, change in clay mineralogy, or change in sorting provide the necessary lithologic criteria for separating the units.

Thickness and Areal Extent

Sediments assigned to the Peace River Formation occur over much of the southern half of the Florida peninsula. The top of the unit ranges from a maximum known elevation of +175 feet (+53 meters) MSL in Polk County to greater than -150 feet (-46 meters) MSL in part of Collier, Dade, Broward, and Palm Beach Counties (Figure 52). The thickness of this unit varies to more than 650 feet (198 meters) in parts of Martin and Palm Beach Counties (Figure 53). This thickness, which is taken from several sets of cuttings in the area, seems anomalously thick. Thicknesses of 400 feet (122 meters) or greater occur in eastern Glades County along the western edge of Lake Okeechobee (Figure 53).

Although the Peace River Formation occurs over most of the southern portion of the state, it is absent from the Ocala Platform and the Sanford High (Figures 4, 52 and 53). It is also absent, possibly due to erosion, from portions of Hillsborough, Pinellas, Manatee and Sarasota Counties (Figures 52 and 53). It dips east, south and west off the southern nose of the Ocala Platform (an area referred to as the Central Florida Platform by Hall [1983]). South of this area, the dip is primarily south and southeast at approximately 8 feet per mile (1.3 meters per kilometer) (Figure 52). Local variations of dip direction and degree are common.

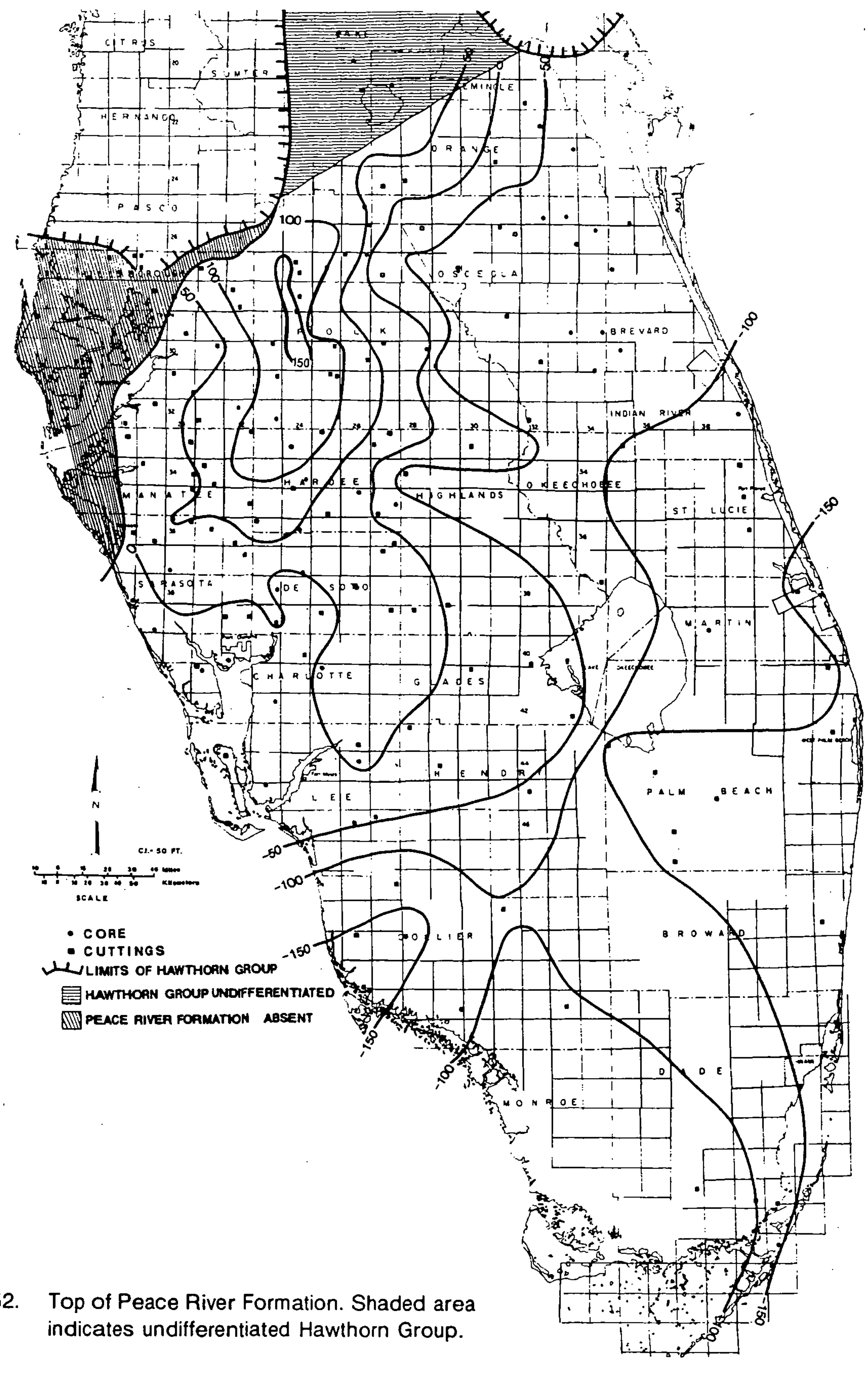


Figure 52. Top of Peace River Formation. Shaded area indicates undifferentiated Hawthorn Group.

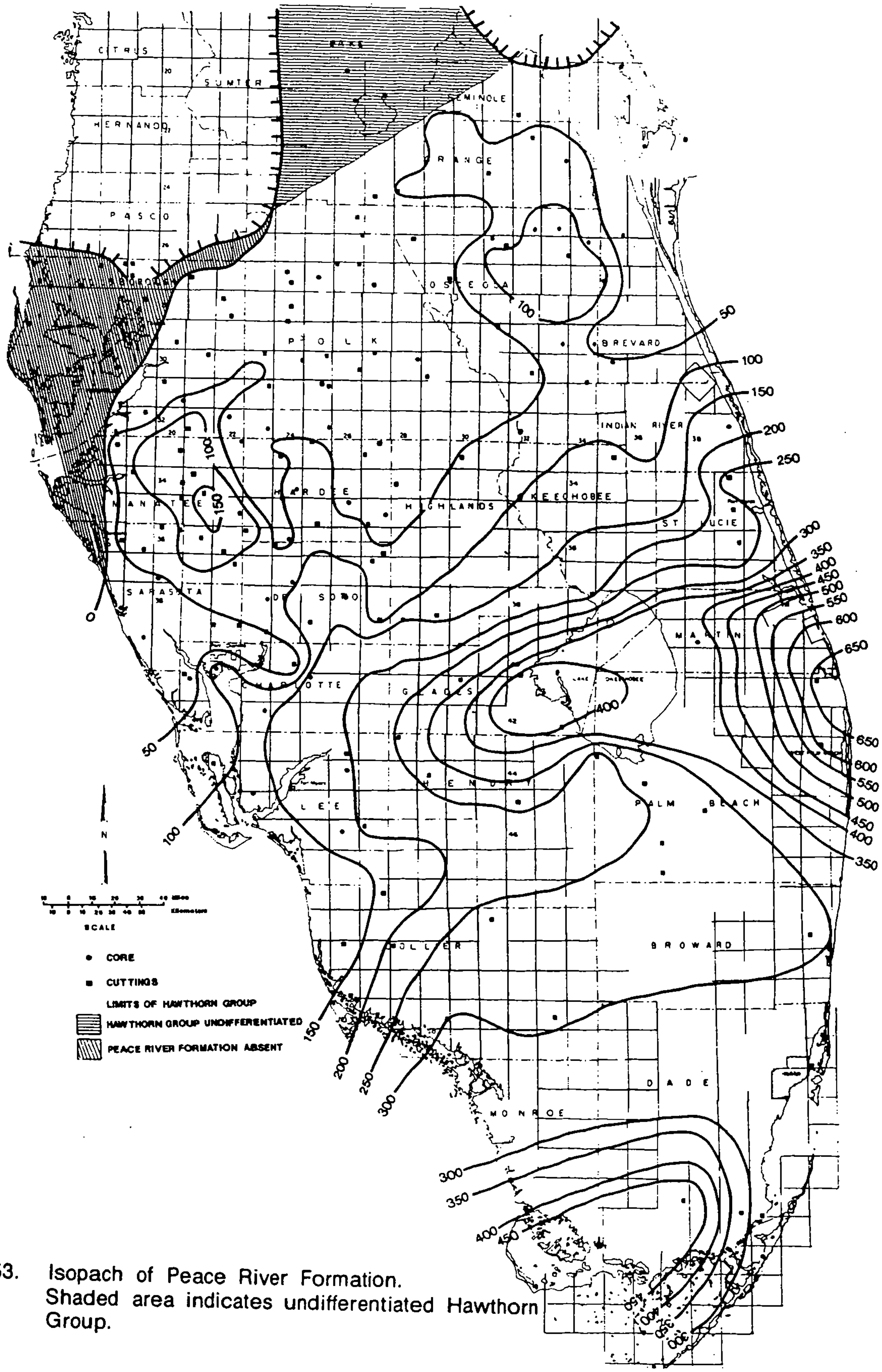


Figure 53. Isopach of Peace River Formation. Shaded area indicates undifferentiated Hawthorn Group.

Age and Correlation

The Peace River Formation often contains well preserved fossils that include vertebrates, diatoms, and foraminifera. As a result, the range of ages that this unit encompasses can often be documented.

Vertebrate fossils are frequently exposed during mining operations in the central Florida phosphate mines. The oldest, a limited fauna tentatively assigned an early to middle Barstovian age (late Early to late Middle Miocene) (Webb and Crissinger, 1983), was collected from the lowest strata of the Peace River Formation, just above its contact with the older Arcadia Formation. These fossils suggest a possible latest Early to early Middle Miocene age for the lowest part of the Peace River. This author has found no record of Late Barstovian or Clarendonian vertebrate sites in the Peace River Formation of southern Florida. The next younger vertebrates from the phosphate mining area are those known as the Lower Bone Valley fauna. These are regarded as being of Early Hemphillian age (medial to late Late Miocene) according to MacFadden and Webb (1982). The Bone Valley Member, also contains the Upper Bone Valley Fauna, for which a Late Hemphillian age has been assigned. This fauna is discussed further in the section of the Bone Valley Member. Another assemblage of vertebrate fossils, known as the Manatee local fauna, was collected *in situ* at the Manatee River Dam site, just east of Bradenton in Manatee County. These fossils, assigned an early Late (or medial) Hemphillian age, came from beds only 6 to 10 feet (1.8 to 3.0 meters) above present sea level (MacFadden and Webb, 1982, p. 197).

Marine invertebrates provide additional information about the age of the Peace River Formation in other parts of southern Florida. Diatoms identified by Hoenstine (personal communication, 1979) from core W-10761 in Charlotte County indicate a Middle Miocene age for Peace River sediments at -92 feet (-28 meters) below present sea level. According to Huddlestun (personal communication, 1983), foraminifera in W-15286 in Lee County suggest an age no younger than earliest Pliocene for sediments at -132 feet (-40.5 meters) MSL. Huddlestun also suggests a Late Miocene age (early to middle Tortonian age) for Peace River sediments at -405 to -417 feet (-124 to 127.5 meters) MSL in W-15246 in Martin County. He also indicated an earliest Pliocene age for the Peace River sediments between -175 feet (-53.5 meters) MSL and -437 feet (-133.5 meters) MSL in W-15493 in Monroe County.

When considering the depths from which some of these invertebrates are reported, the reader should bear in mind that the southern half of the peninsula is known to be a subsiding area, with the degree of subsidence varying from minimal in the northern area to maximum at the southernmost tip of the peninsula and in the Florida Keys. The present subsea elevation of the strata that contain these marine invertebrates is therefore not necessarily the same as the elevation of the strata in relation to sea level at time of deposition.

From the preceding records, the Peace River Formation is thought to range in age from possibly latest Early or early Middle Miocene for the oldest sediments to early Pliocene for the youngest.

Huddlestun et al. (1982) informally proposed the name "Indian River beds" of the Hawthorn Group (later changed to Wabasso beds) for an interval of sediments in core W-13958, Indian River County. They reported diatoms and planktonic foraminifera indicative of a late Early Pliocene age for the strata. Their age assignment suggests that the Wabasso beds may be slightly younger than the uppermost Peace River strata.

The lower part of the Peace River Formation is here correlated with the Coosawhatchie and Statenville formations of northern Florida (Figure 19). This is based partly on stratigraphic position, and partly on ages suggested by the Middle Miocene diatoms, and the tentative Early to Middle Barstovian age for the vertebrates in the lowest beds of the Peace River.

Huddlestun (personal communication, 1983) suggests that the upper strata of the Peace River are slightly older than the Jackson Bluff Formation in the Panhandle. They are also slightly older than the Tamiami Formation of southern Florida as restricted herein.

Discussion

For years the Peace River Formation has been identified and mapped as the upper siliciclastic unit of the Hawthorn Formation in south Florida. It is simply the phosphatic quartz sands and clays that overlie

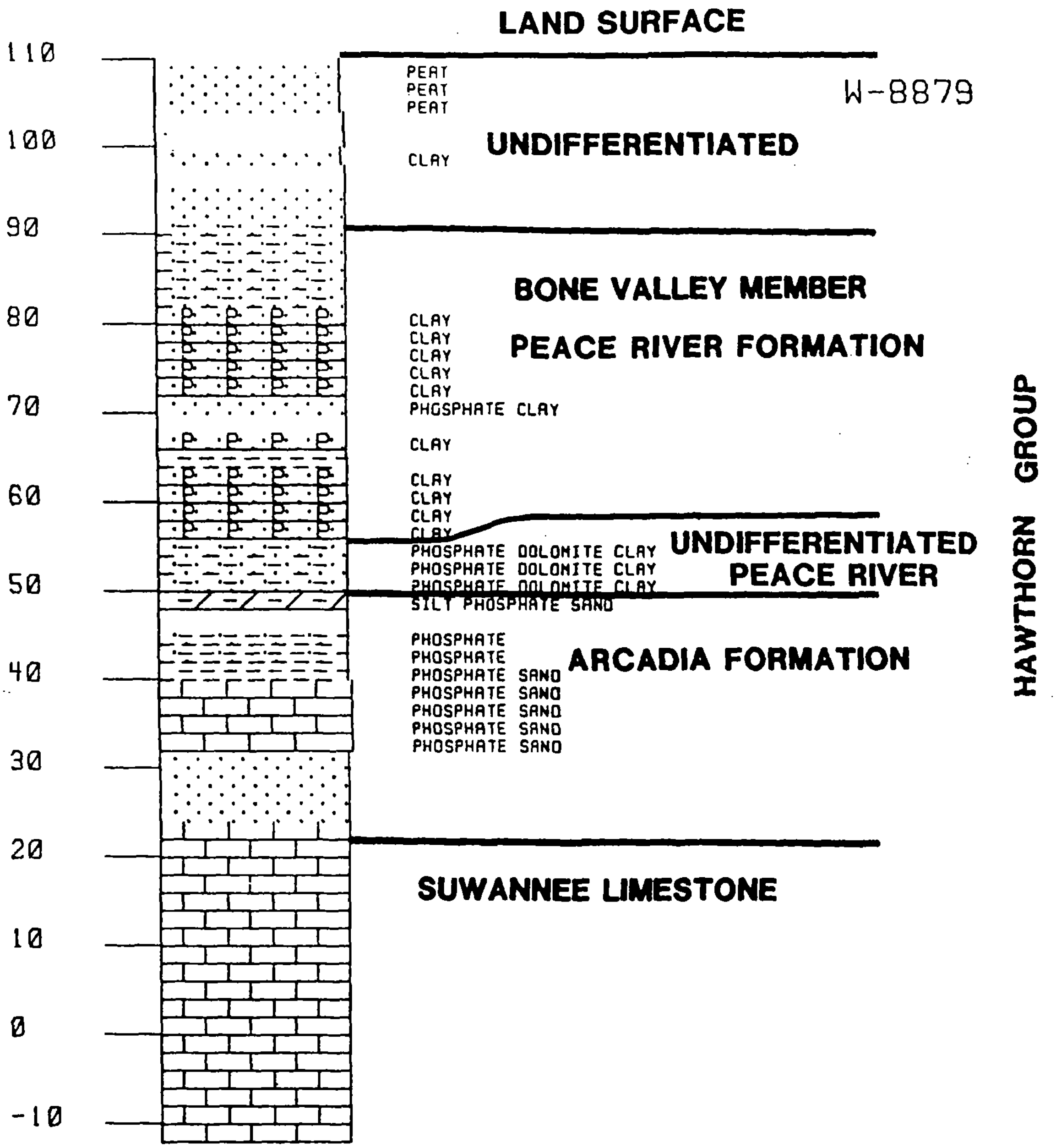


Figure 54. Reference core for the Bone Valley Member of Peace River Formation, Griffin #2, W-8879, Polk County (Lithologic legend Appendix A).

and grade into the Hawthorn carbonate section (here referred to as the Arcadia Formation). In this report the name Peace River Formation is formally proposed for this section including the Bone Valley Formation of former usage, the lower Tamiami Formation of Parker, et al. (1955) and the Murdock Station and Bayshore Clay members of the Tamiami of Hunter (1968).

Strata currently assigned to the Peace River Formation in southernmost Florida and along the southeastern coast include sediments that are Messinian to Zanclian, latest Miocene to earliest Pliocene in age. These sediments may be age equivalent with the uppermost bed of the Bone Valley Member. Ad-

mittedly the data base in these areas is relatively poor. Future investigations may provide the core data necessary to further describe the sections.

BONE VALLEY MEMBER OF THE PEACE RIVER FORMATION

Definition and Type Locality

The Bone Valley Formation of former usage is demoted herein to member status within the Peace River Formation of the Hawthorn Group. The status reduction is suggested due to the limited areal extent of this unit, to the gradational nature of its boundaries (both lateral and vertical) with the Peace River Formation, and to its lithologic similarities to the Peace River Formation. This unit directly overlies the Arcadia Formation in some areas but overlies and interfingers with the upper Peace River Formation in other areas (Figure 55).

The type area designated by Matson and Clapp (1909) consists of phosphate mines west of Bartow in Polk County, but no individual type section was proposed. More complete sections of the Bone Valley Member are presently available in present-day phosphate mines than were accessible when the unit was

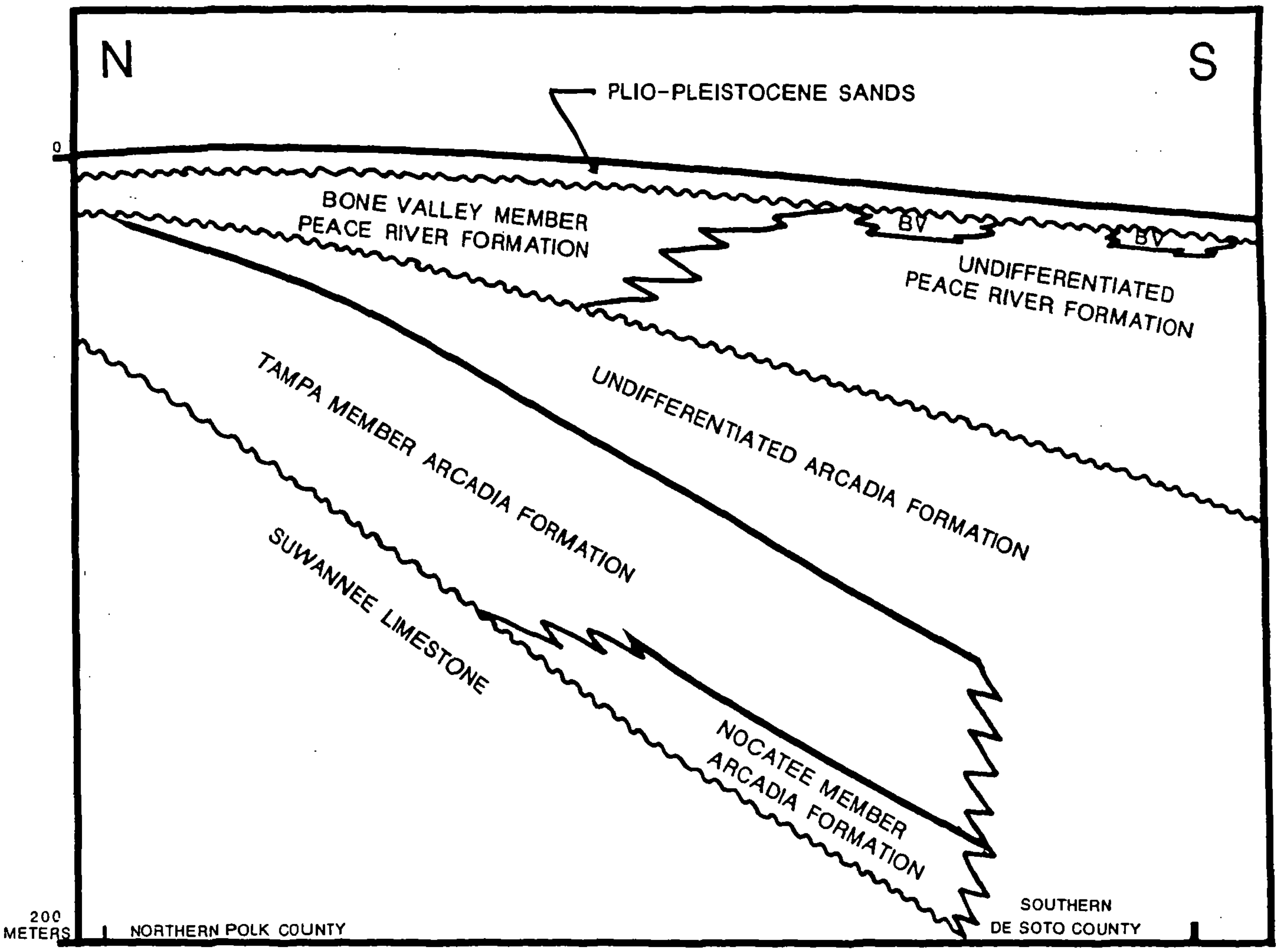


Figure 55. Schematic diagram showing relationship of lithostratigraphic units in southern Florida.

described. Unfortunately, the mine sections are constantly being changed by the mining operations and a definite type section is impossible to erect. As a result, the Bone Valley Member type area remains designated the current exposures in mines west of Bartow in Polk County.

It is interesting to note that the original "Bone Valley Gravel" of Matson and Clapp (1909) was probably limited to only the uppermost gravel bed of the Bone Valley Formation as it is currently used in the phosphate district. As mining methods improved deeper pits were dug exposing more of the phosphorite section and the accepted definition of the Bone Valley was expanded to include these sediments.

A principal reference section in a core, W-8879 (NE 1/4, SW 1/4 Section 24, Township 29S, Range 24E, Polk County), near Bartow is suggested as being representative of this unit. In this core the Bone Valley Member occurs between 91.5 feet (28 meters) MSL and 56 feet (17 meters) MSL (surface elevation is 110 feet [33.5 meters]) (Figure 54).

Lithology

Throughout its extent, the Bone Valley Member is a clastic unit. It consists of pebble- or gravel-sized phosphate fragments and sand-sized phosphate grains in a matrix of quartz sand and clay. Percentages of the various constituents vary widely.

The occurrence of phosphate gravels in the Bone Valley is the most lithologically important factor in the separation of the member from the remainder of the Peace River Formation. Phosphorite sands are also present, often as the most abundant phosphate size fraction. The phosphate grains range in color from white (N 9), where they have been leached, to black (N 1). Commonly the larger phosphate clasts appear to be replacement of carbonate by phosphate.

The quartz sands occur intimately mixed with the phosphate and clays in the Bone Valley Member. Only in part of the leached zone are phosphate grains absent from the sands. A leached zone develops where the phosphate grains are removed by groundwater dissolution. Other phosphate minerals are often deposited in the sands, weakly cementing them. Clays in this zone are also altered. The sands range from very fine grained to very coarse with some zones containing quartz pebbles and cobbles. Colors of the sands range from white (N 9) and light brown (5 YR 6/4) in the leached zone to light olive gray (5 Y 6/1) in the more clayey sections and to dark gray (N 3) in the highly phosphatic sections.

Clays characteristically occur as matrix materials but also occur as discrete beds. The clay beds vary in the amount of accessory minerals present, occasionally occurring as relatively pure clay with very little sand or phosphate grains. The clay beds often occur at the base of the Bone Valley and are referred to in the phosphate district as "bed clays." The "bed clays" have been interpreted by some as being the "residuum of the argillaceous carbonate rock of the Hawthorn..." (Altschuler et al., 1964). Other clay occurrences in the Bone Valley have been interpreted as possible products of alkaline lake deposition (Strom and Upchurch, 1983). Colors of the clay beds exposed in the mines range from white (N 9) to yellowish gray (5 Y 8/1), light brown (5 YR 6/4) and blue green (5 BG 7/2). In cores, the colors show a similar range plus olive grays (5 Y 6/1 and 5 Y 4/1). Beds of carbonate rubble often occur at the base of the "bed clay."

Bedding in the Bone Valley Member varies from faintly stratified to strongly cross bedded. Graded bedding is common throughout the unit, although it is often not well developed. The poorly stratified units are typically more clayey and poorly-sorted, while the crossbedded sections are moderately to well sorted and generally lack finer grained materials (silts and clays). A mottled appearance to the sediment is not typical in the Bone Valley Member but becomes apparent in the underlying undifferentiated Peace River sediments.

The very phosphatic section of the Bone Valley Member grades upward into slightly phosphatic to nonphosphatic clayey sands. These clayey sands have been referred to as the Upper Bone Valley (Altschuler et al., 1964). Bedding is typically massive. In this investigation this section is placed in the Bone Valley as the uppermost sediments, but is not given a separate bed name. This section often contains the "leached zone" which has been altered, often intensely, by groundwater, removing all the included phosphate.

Subjacent and Suprajacent Units

The Bone Valley Member disconformably overlies the Arcadia Formation throughout much of its extent. In the areas furthest updip (Figure 55), the lower Arcadia (possibly the Tampa Member in some cases) immediately underlies the Bone Valley. In southernmost Polk and adjacent parts of Hardee and Manatee counties, the Bone Valley grades laterally, and to some extent vertically, into the undifferentiated Peace River Formation. In this area the Bone Valley often lies on the Peace River and the differentiation between the two becomes difficult (Figure 55). These relationships and those with the overlying units are shown in Figures 35 through 40.

The characteristic Bone Valley section (if such could be seen in a single pit wall or core) consists of a basal gravelly unit lying on either undifferentiated Peace River Formation or Arcadia Formation. This is overlain by a "middle feed" unit of sand-sized material with little gravel which, in turn, is overlain by the upper gravels. When the basal gravels are present it is quite simple to separate the Bone Valley from the undifferentiated Peace River Formation. However, if the basal gravels are absent and the middle unit of the Bone Valley lies on the Peace River sediments, it often is not possible to accurately separate the two beds, and placement of the boundary becomes arbitrary.

The Bone Valley Member is unconformably overlain throughout its extent by unnamed sands. These sands often appear to grade into the Bone Valley due to the obliteration of the contact by ground-water leaching and reworking. The unnamed sands have often been referred to as Pleistocene or Plio-Pleistocene in age.

Thickness and Areal Extent

The Bone Valley Member occurs at elevations as high as 175 feet above sea level (53 meters) in southwestern Polk County (Figure 56). Over the majority of its areal extent the Bone Valley member occurs above 100 feet (30.5 meters) MSL. The lowest elevations of the upper surface of the Bone Valley occur near the limits of the member on the east, south and west (Figure 56). This unit attains a maximum thickness of just over 50 feet (15 meters) in southwest Polk County, from which it thins in all directions (Figure 57). Locally, the Bone Valley may thicken abruptly into karst features.

The upper surface of the Bone Valley Member dips in all directions away from the highest area at less than 5 feet per mile (0.9 meters per kilometer). Individual beds within the Bone Valley appear to have a slight "seaward" dip (Matson and Clapp, 1909).

This unit extends over much of the western half of Polk County, the eastern one-third of Hillsborough County, northeast Manatee County and northwest to north-central Hardee County (Figures 56 and 57). Outside this area individual beds of Bone Valley lithology occur intermixed with undifferentiated Peace River sediments, but are not differentiated.

Age and Correlation

Vertebrate remains are frequently exposed during mining operations in the central Florida phosphate mines, and are probably the source of the name, Bone Valley. The ages assigned to the Bone Valley Member are derived entirely from these vertebrate fossils.

The oldest, a limited fauna tentatively assigned an early to Middle Barstovian age (Webb and Crissinger, 1983), was collected from the lowest strata of the Bone Valley Member, just above its contact with the older Arcadia Formation. These fossils suggest a possible latest Early to early Middle Miocene age for the lowest part of the Bone Valley. This author has found no record of Late Barstovian vertebrate sites in the Bone Valley Member of southern Florida. The next younger vertebrates from the phosphate mining area are those known as the "Lower Bone Valley Fauna." These are regarded as being of Early Hemphillian age (medial to late Late Miocene) (MacFadden and Webb, 1982). The youngest vertebrate assemblage, known as the Upper Bone Valley Fauna, occurs in marine sediments deposited above an unconformity thought to represent the Messinian regressive event. MacFadden and Webb (1982) indicate a Late Hemphillian age for these animals. Because of the unconformity, it is suggested that the

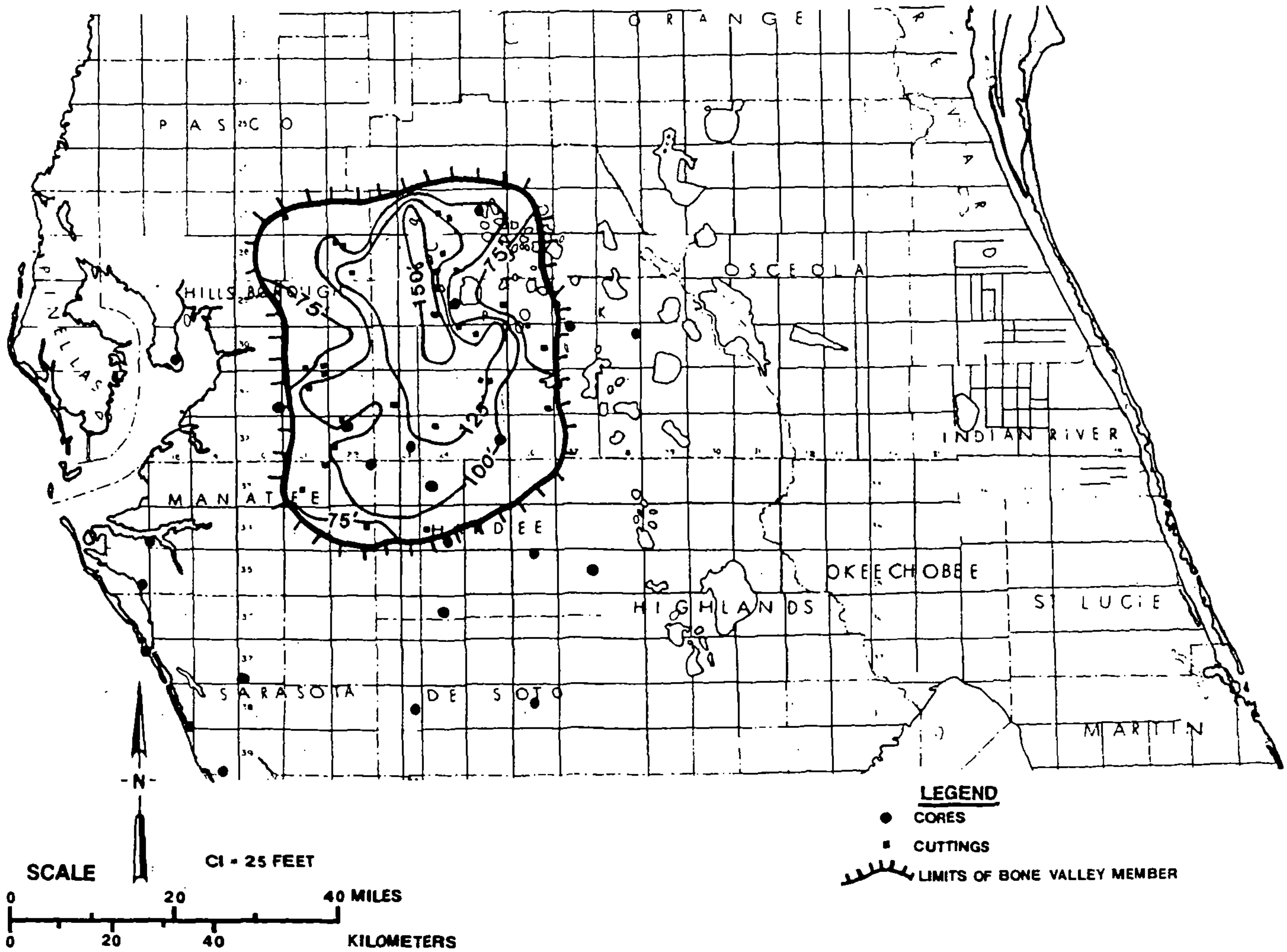


Figure 56. Top of Bone Valley Member.

age of the uppermost Bone Valley strata is probably Early Zanclian (very Early Pliocene; see Figure 73). These sediments are discussed by Webb and Crissinger (1983) as reworked channel deposits ("drift rock" of phosphate mining terminology), also being of Late Hemphillian age. They further reported that Pleistocene vertebrates have been collected from younger channel fills that contain reworked parts of the Bone Valley Member.

The Early Pliocene strata of the Bone Valley Member that occur above the unconformity seem to have no exact correlatives that have been identified with certainty in Florida or the Southeast Georgia Embayment.

Huddlestun (personal communication, 1983) suggests a correlation of the Bone Valley Member to the hard rock phosphates of central Florida based on vertebrate faunas. The Bone Valley also correlates to part of the Intracoastal Formation in the Apalachicola Embayment (Schmidt, 1984). Part of the Bone Valley Member correlates with the Coosawhatchie and Statenville Formations of North Florida and Georgia and the Pungo River Formation of North Carolina. A portion of the Bone valley correlates with Huddlestun's (in press) Screven Formation in the Georgia Coastal Plain.

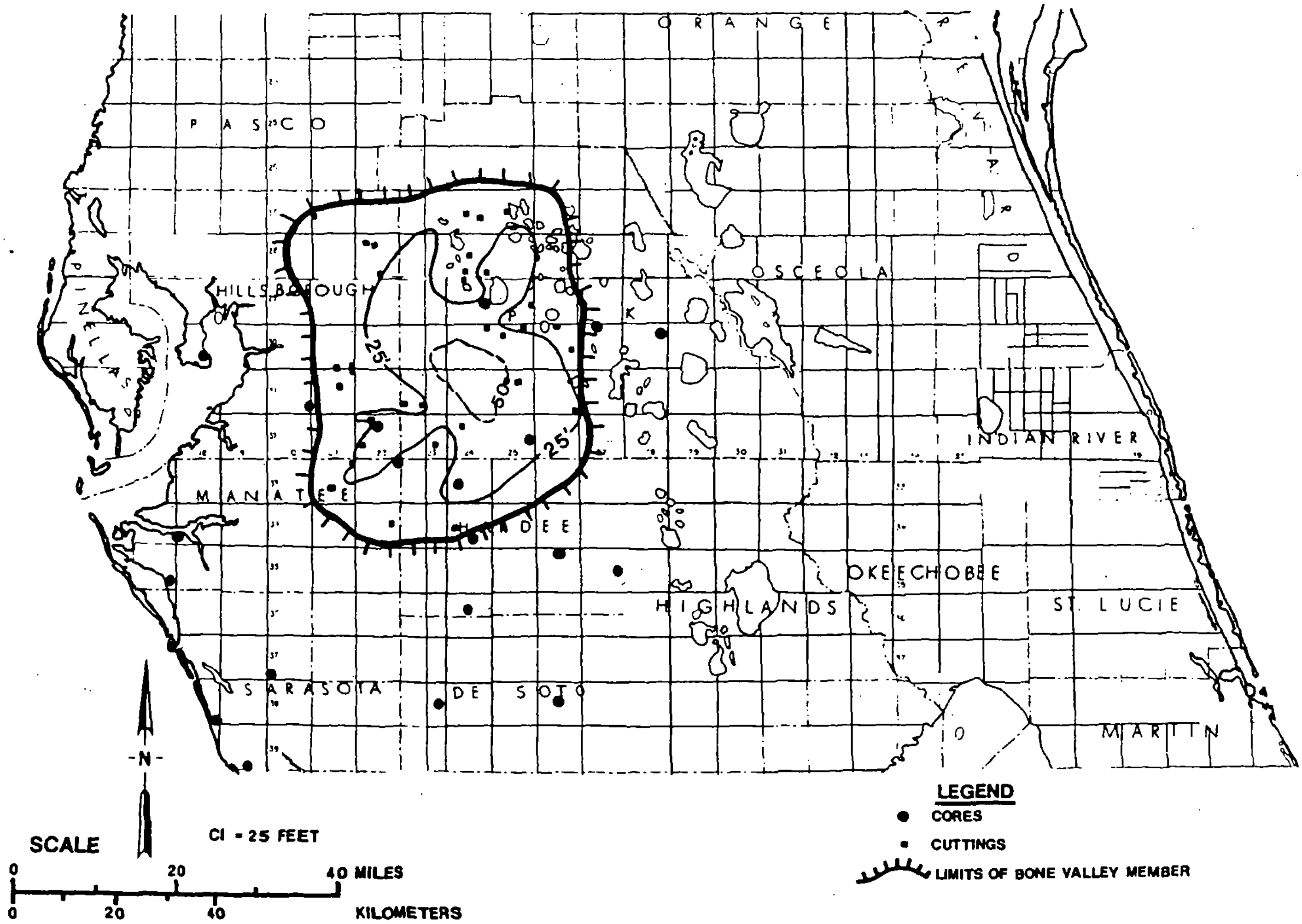


Figure 57. Isopach of Bone Valley Member.

Discussion

The Bone Valley section has been recognized for years due to its economic importance. However, as previously mentioned, its limited areal extent does not warrant formational status. The preceding discussion of the Bone Valley indicates distinct similarities between parts of the Bone Valley Member and the undifferentiated Peace River Formation. Geologists familiar with the geologic section in the phosphate district readily recognize the similarities and many have accepted the association of these units.

One source of discussion concerning the placement of the entire Bone Valey in the Peace River Formation and the Hawthorn Group is the occurrence of a major unconformity within this section. The unconformity spans much of the Late Miocene. Without the aid of dateable fossils, it is normally not possible to separate the pre-unconformity gravels from the post-unconformity gravels. The argument has been presented that the post-unconformity Bone Valley sediments should not be included in the Peace River Formation or the Hawthorn Group. However, based on lithologic similarities on either side of the nonconformity and their stratigraphic position it is perfectly acceptable under the North American Stratigraphic Code, Article 23d (NACSN, 1983) to place all these sediments in a single unit.

In light of this argument it is interesting to note that the classical Bone Valley "Formation" as originally described by Matson and Clapp (1909), included only the post-Messinian gravels. This was the only portion of the section normally exposed as a result of the old mining methods. As flotation methods began being used to concentrate the phosphate, mining went deeper into the phosphate-bearing strata. As the deeper lithologies were exposed, most were incorporated into the Bone Valley "Formation" thereby expanding the time frame and the definition of the unit.

EASTERN FLORIDA PANHANDLE

The Hawthorn Group extends northwestward from the Ocala Platform across the eastern portion of the Florida panhandle as far west as the Apalachicola River in Gadsden and Liberty Counties. Sediments of the Hawthorn Group have not been identified west of the Apalachicola River on the west side of the Gulf Trough (Huddlestun and Hunter, 1982). These sediments are thickest in the Gulf Trough and thin dramatically on the flanks.

Lithologically, much of the Hawthorn Group in the eastern panhandle is quite different from the Hawthorn sediments of the peninsular area. The most obvious difference is the decreased phosphate content throughout the section. In Madison, Jefferson and part of Leon Counties the dominant lithology is sandy clay to very clayey sand. Carbonate content increases in the Gulf Trough area, where the lithologies become more similar to those of the northeastern peninsular area in many respects.

Stratigraphically, the sediments under consideration here are assigned to the Torreya Formation of the Hawthorn Group (Figure 58). Unfortunately, core data to further refine the stratigraphy of these sediments in the eastern panhandle do not exist at this time either in northern Florida or southern Georgia.

TORREYA FORMATION

Definition and Type Section

The Torreya Formation was described by Banks and Hunter (1973) as consisting of post-Tampa, pre-Chipola (Early Miocene) age deposits in the eastern Florida panhandle. In defining this unit Banks and Hunter (1973) restricted the use of the Hawthorn Formation by removing from it the sediments of the Torreya. However, they did not clearly distinguish between the two units lithologically due to the paucity of data available at the time.

Huddlestun and Hunter (1982) suggested the revision of the definition of the Torreya to include all deposits previously referred to the Hawthorn Formation in the eastern Florida panhandle. They regarded the Torreya as identical to the Hawthorn Formation of former usage. The Torreya is the only formation currently recognized as part of the Hawthorn Group in this area. It includes two named members: the Dogtown and the Sopchoppy (Figure 58).

The type section designated by Banks and Hunter (1973) is located at Rock Bluff, Liberty County, Florida, in the Torreya State Park from which the formational name is derived. Rock Bluff is located on the Apalachicola River in the SW¼, Section 17, Township 2 North, Range 7 West. A complete description of this outcrop is available in Banks and Hunter (1973). For the purpose of this study, reference sections are designated in cores W-6611, SE¼, NE¼ Section 23, Township 2N, Range 7W, Liberty County (Figure 59); W-7472, NW¼, SE¼ Section 19, Township 2N, Range 3W, Gadsden County (Figure 60); and W-6998, SE¼, NW¼ Section 8, Township 2N, Range 2E, Leon County (Figure 61).

Lithology

The Torreya Formation of the eastern Florida panhandle is typically a siliciclastic unit with increasing amounts of carbonate in the lower portion of the section, particularly in the Gulf Trough area. The siliciclastic portion varies from a very fine to medium grained, clayey quartz sand to a variably quartz-sandy, silty clay often containing a minor but variable carbonate component (either calcareous or

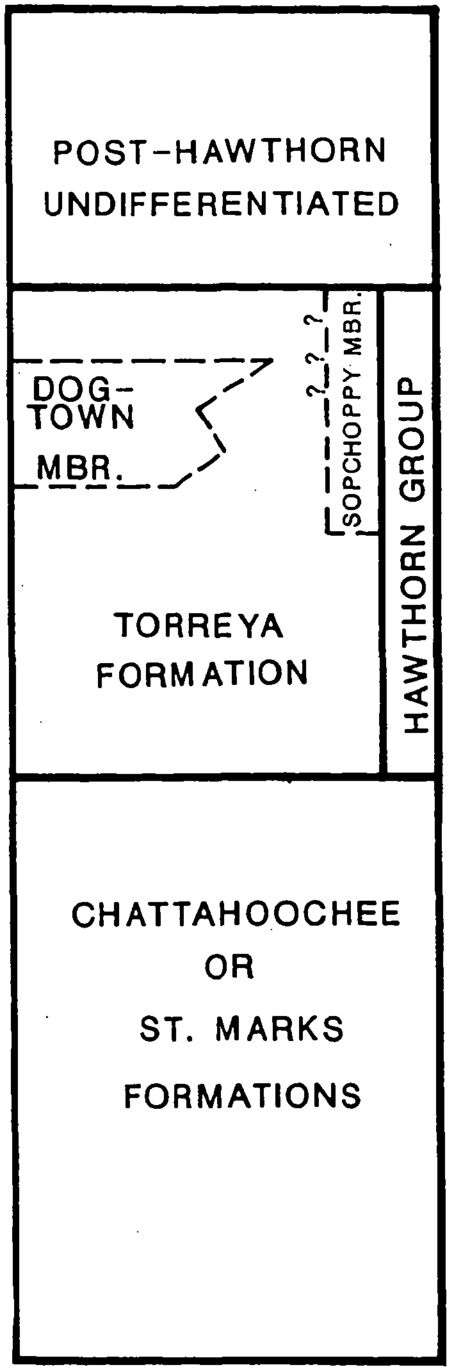


Figure 58. Lithostratigraphic units of the Hawthorn Group in the eastern Florida panhandle.

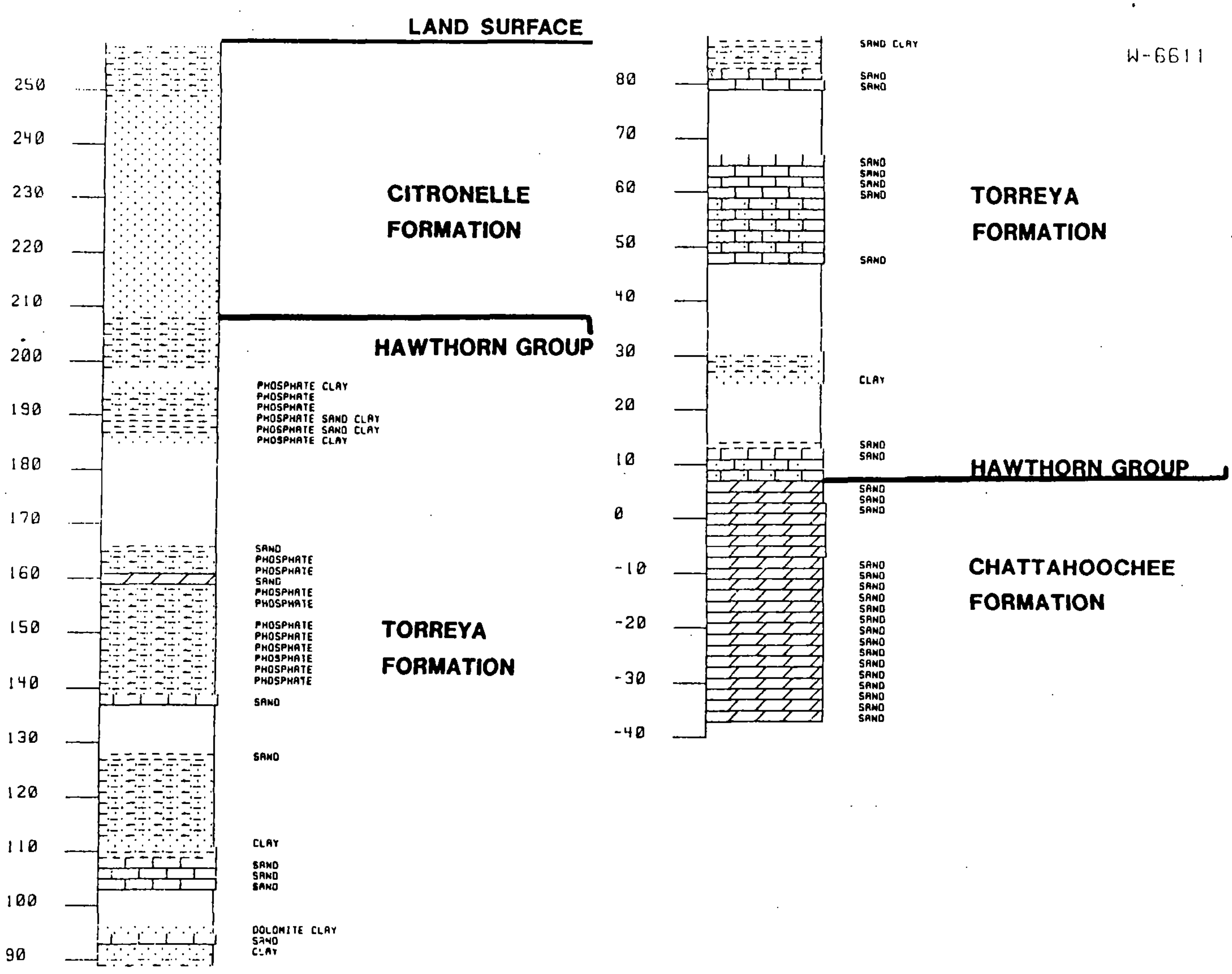


Figure 59. Reference core for the Torreya Formation, Rock Bluff #1, W-6611, Liberty County (Lithologic legend Appendix A).

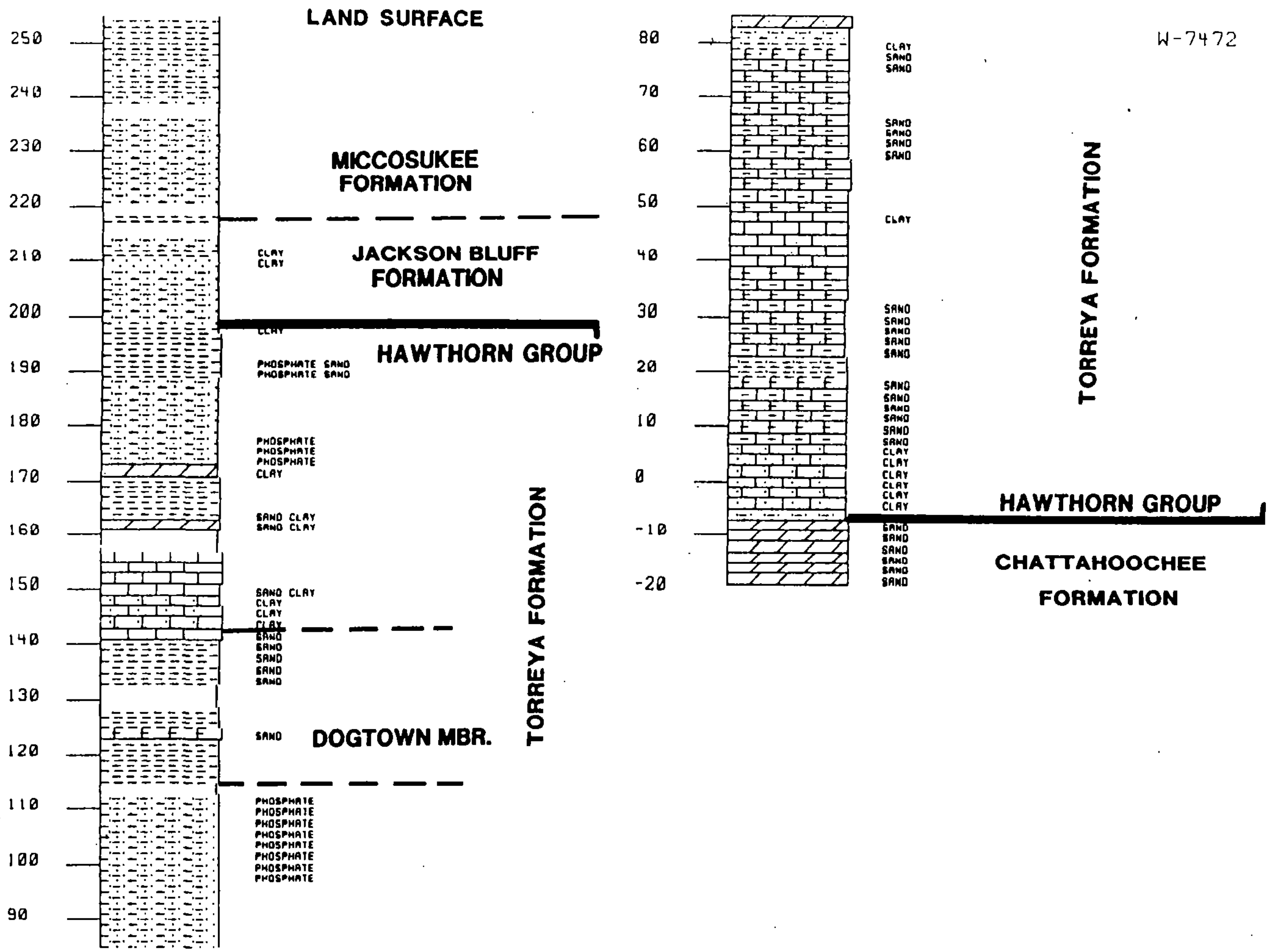


Figure 60. Reference core for the Torreya Formation, Owenby #1, W-7472, Gadsden County (Lithologic legend Appendix A).

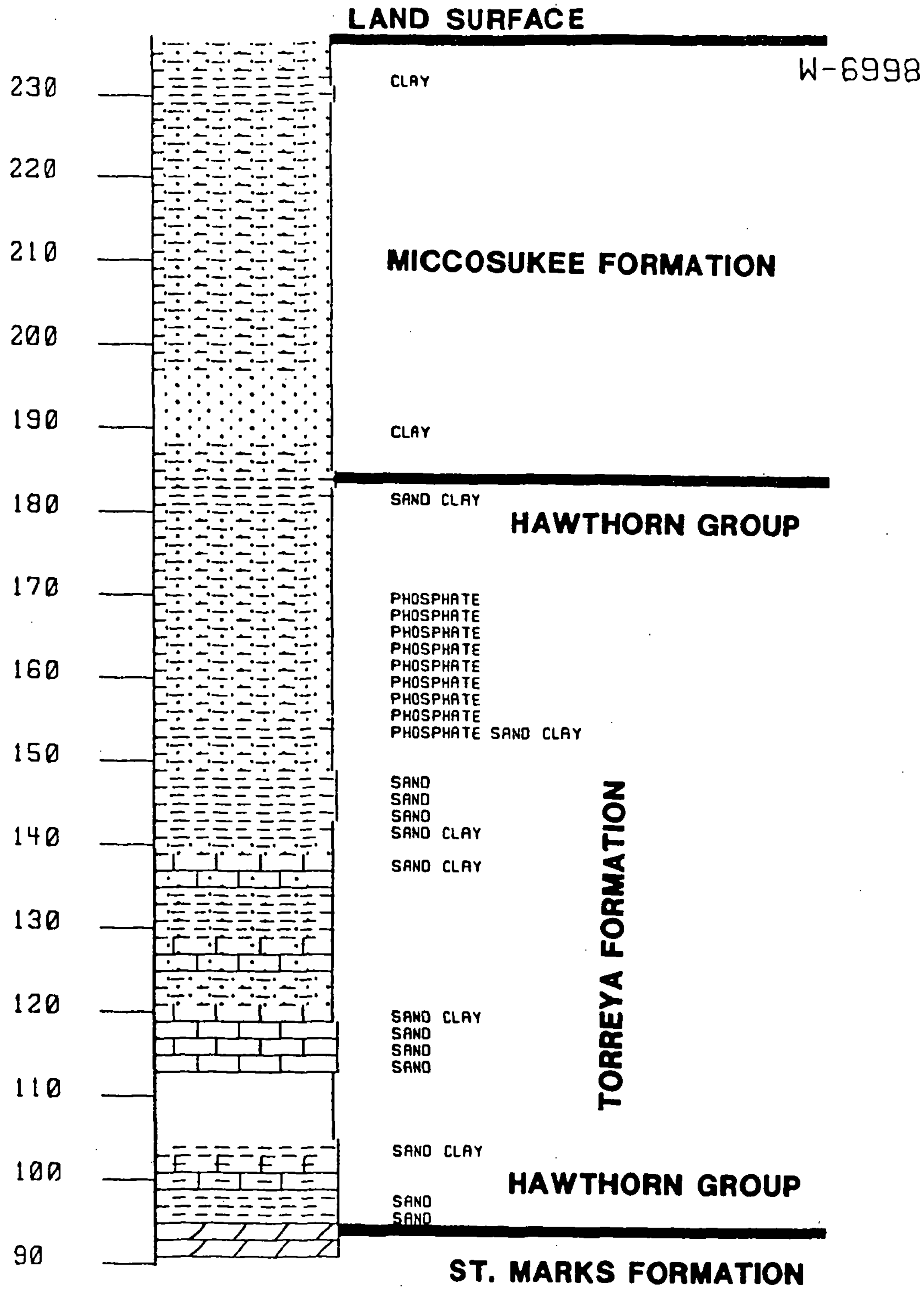


Figure 61. Reference core for the Torreya Formation, Goode #1, W-6998, Leon County (Lithologic legend Appendix A).

dolomitic). Phosphate grains are a common but minor lithologic component of the siliciclastic beds and are often absent. Induration varies from poor to moderate, generally in direct relation to the relative amounts of clay and/or carbonate present. The colors in the unweathered siliciclastic beds range from white (N 9) and yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). In a more weathered section the sediments appear mottled and are grayish-red (10 R 4/2) to grayish orange (10 YR 7/4) in color.

The carbonate portion of the Torreya Formation typically is a variably quartz-sandy, clayey limestone which occasionally may be dolomitic. As noted by Huddlestun and Hunter (1982), the Torreya is the only formation of the Hawthorn Group in north Florida and Georgia where limestone is an important and consistent component of the lithology. Minor amounts of phosphate are present in limestones of the upper Torreya. Quartz sand content varies drastically and grades into calcareous quartz sands. Induration is usually moderate but is variable. Color ranges from white (N 9) to light olive-gray (5 Y 6/1). The carbonate sediments are often fossiliferous and commonly have abundant molds and casts of mollusks.

Clays are an important lithologic component of the Torreya Formation particularly in the upper part of the unit. The clays are predominantly palygorskite and smectite with minor sepiolite, illite and kaolinite (Weaver and Beck, 1977). Weaver and Beck (1977) recognized the variability of the clay mineralogy in that some intervals may be dominated by palygorskite while others may be predominantly smectite or, more rarely, sepiolite. Ogden (1978) recognized that palygorskite was the major and occasionally the sole clay mineral constituent in the southern portion (Florida) of the fuller's earth mining district. Other minor lithologic components recognized in the Torreya Formation include feldspar, pyrite, opal-CT, and mica.

Bedding in the Torreya Formation ranges from thin laminae to more massive beds up to 5 feet (1.5 meters) thick (Huddlestun and Hunter, 1982). Bioturbation has had a widely variable effect on the bedding, which ranges from undisturbed to highly bioturbated.

Huddlestun and Hunter (1982) recognized the occurrence of intraformational breccias in the Torreya sediments. The intraclasts are composed of clay or carbonate and are enclosed in a clayey or carbonate matrix. They suggest that the intraclast beds are characteristic of the inner Apalachicola Embayment and the Gulf Trough area, and are a local occurrence, not correlatable throughout the area.

Lithologic variation in the Torreya occurs both laterally and vertically. The lateral variations include 1) more carbonate in the Apalachicola Embayment-Gulf Trough area and 2) the carbonates become dolomitic eastward and northwestward (Huddlestun and Hunter, 1982). Vertical variations recognized within the Torreya Formation include in ascending order 1) a basal carbonate-rich zone; 2) a siliciclastic (quartz sand) sequence that often contains phosphate grains; 3) a clay-rich facies which contains the commercial fullers earth beds (this is the Dogtown Member); 4) a calcareous facies of sandy limestone or calcareous quartz sands (Sopchoppy Member?); and 5) uppermost beds of noncalcareous clays and quartz sand (Huddlestun and Hunter, 1982).

Subjacent and Suprajacent Units

The Torreya Formation is underlain by carbonates that have been referred to as the Chattahoochee Formation and/or St. Marks Formation. Huddlestun and Hunter (1982) refer to these sediments as Chattahoochee. Other investigators, such as Hendry and Sproul (1966) and Yon (1966), placed the sediments in the St. Marks. The contact between these units appears gradational in portions of the Gulf Trough-Apalachicola Embayment area but is disconformable in other areas.

Throughout much of its extent, the Torreya Formation is disconformably overlain by the Citronelle and Miccosukee formations. The Citronelle Formation occurs in the western portion of the area, in parts of Liberty and Gadsden Counties, and grades eastward into the Miccosukee Formation. Near Alum Bluff (W-6901), on the Apalachicola River, the Torreya is overlain disconformably by the Chipola Formation (Banks and Hunter, 1973; Huddlestun and Hunter, 1982). Further south, in Wakulla County, erosional outliers of Jackson Bluff Formation disconformably lie on the Torreya (Banks and Hunter, 1973). Huddlestun and Hunter (1982) state that elsewhere in the eastern panhandle the Torreya Formation is overlain by undifferentiated surficial sands. These relationships are shown in Figure 62.

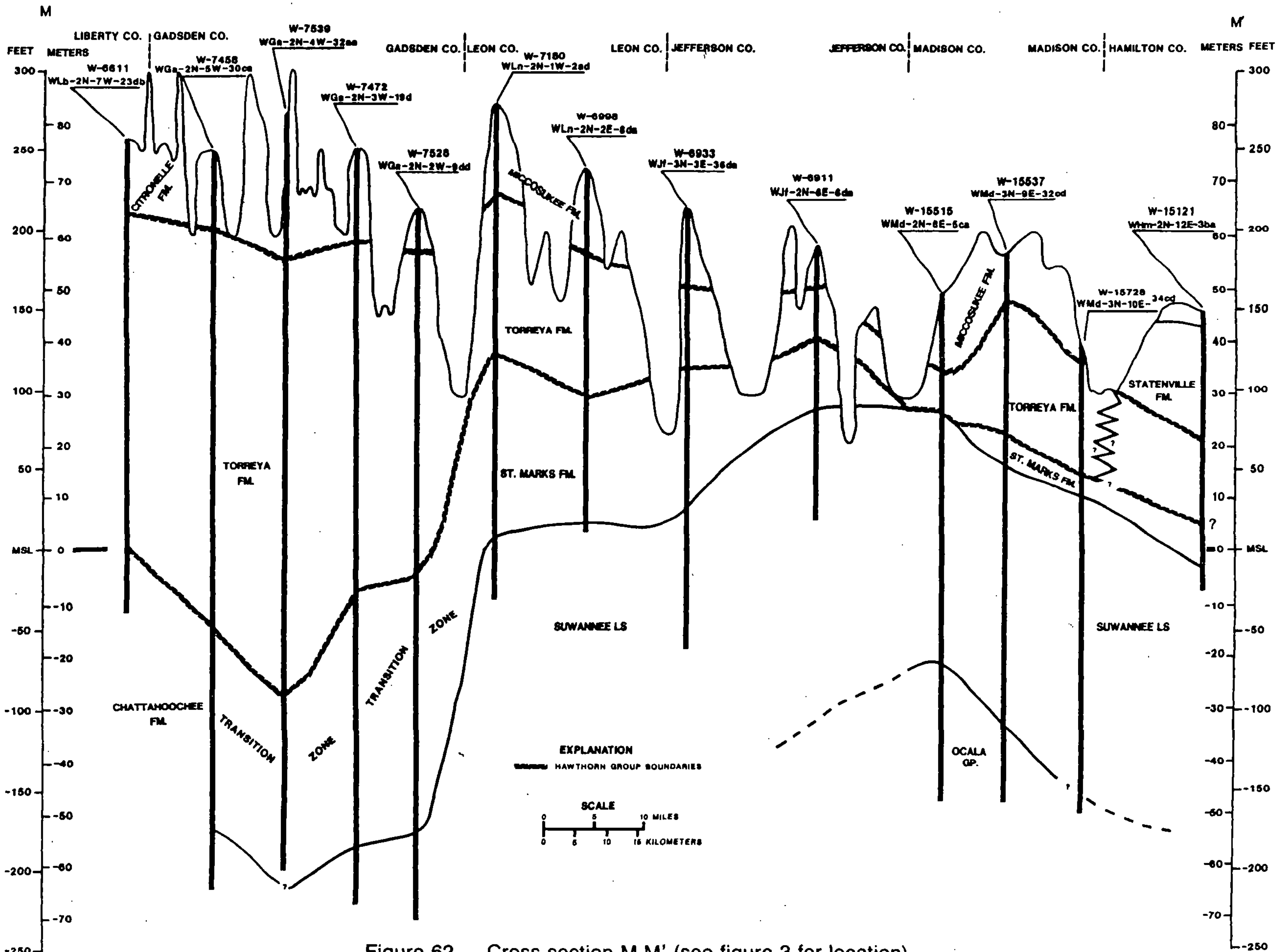


Figure 62. Cross section M-M' (see figure 3 for location).

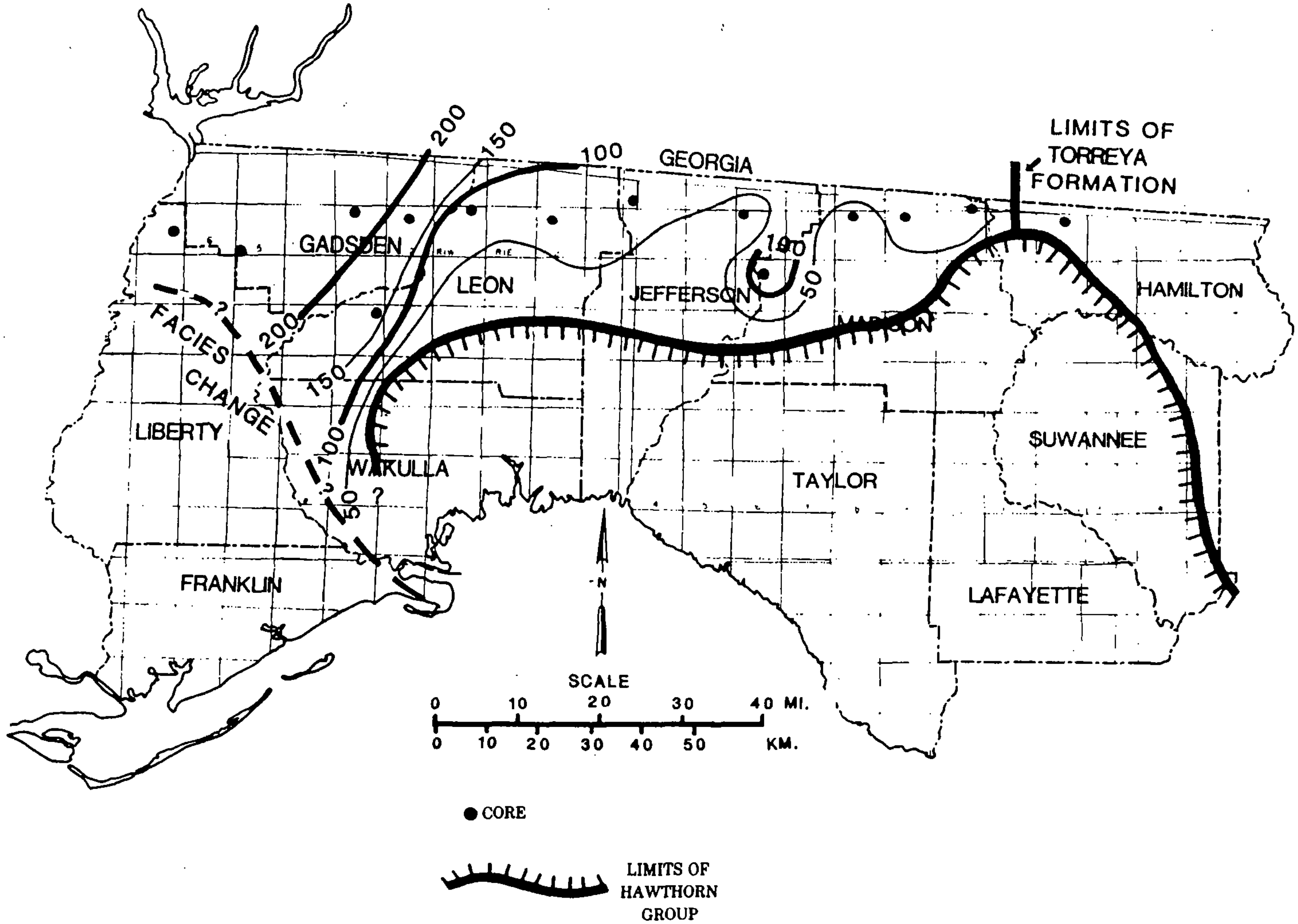


Figure 63. Isopach of the Torreya Formation.

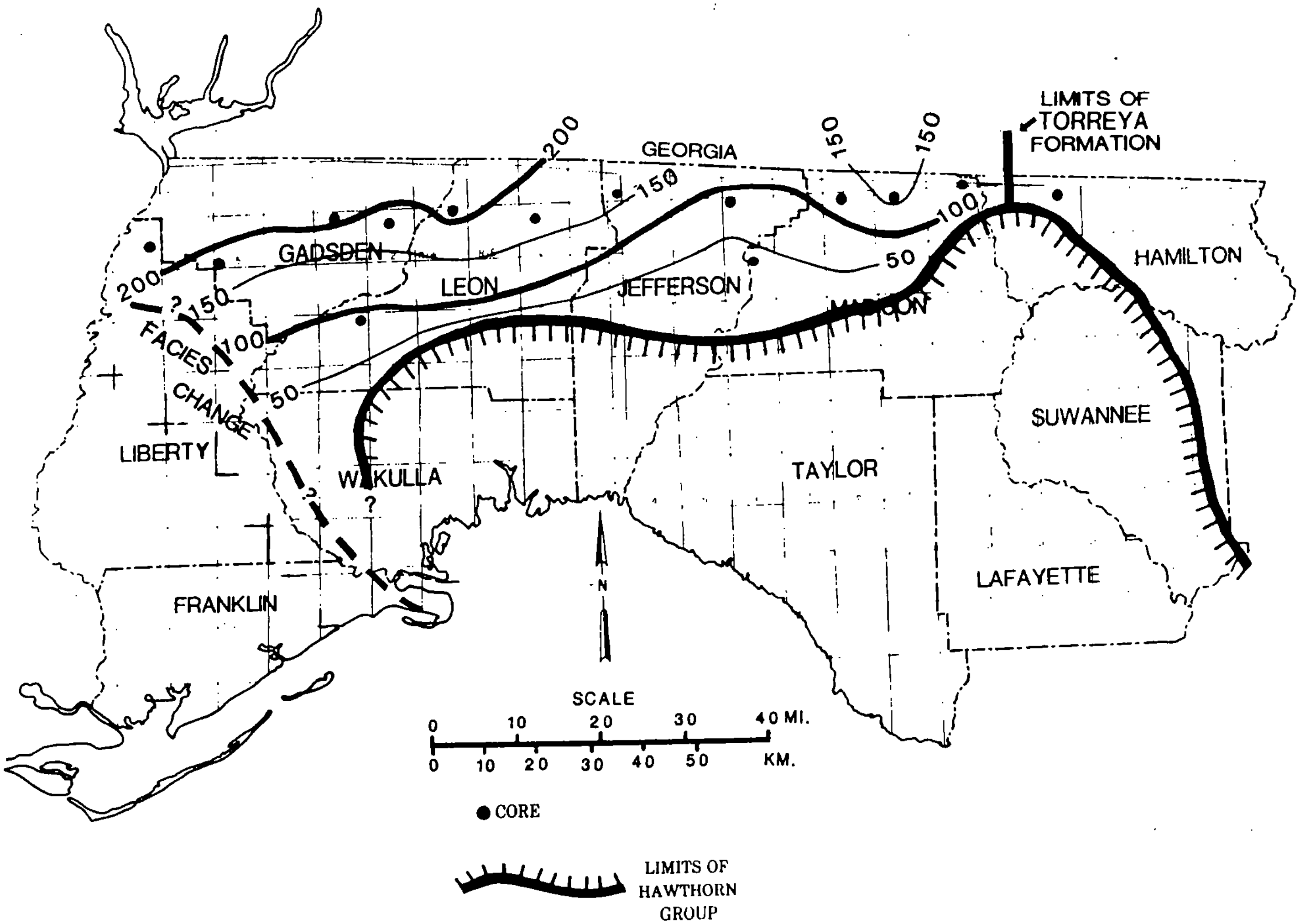


Figure 64. Top of the Torreya Formation.

Thickness and Areal Extent

The Torreya Formation varies considerably in thickness with a maximum of 227 feet (69 meters) in W-7539, Suber #1, Gadsden County, Florida near the axis of the Apalachicola Embayment (Huddlestun and Hunter, 1982). Characteristically, through the eastern panhandle, the thickness varies from 50 feet (15 meters) to 100 feet (30 meters) (Huddlestun and Hunter, 1982) (Figure 63).

The Torreya Formation underlies much of the eastern panhandle as shown in Figures 64 and 65. It occurs in parts of Madison, Jefferson, Leon, Wakulla, Liberty and Gadsden Counties. The Torreya extends northward into south Georgia (Huddlestun and Hunter, 1982), but its full extent is not known. Elevation of the upper surface of the Torreya ranges from less than 50 feet to greater than 200 feet above MSL (Figure 64).

Age and Correlation

Hunter and Huddlestun (1982), Huddlestun and Hunter (1982) and Huddlestun (in press) suggest that the Torreya Formation is middle Early Miocene (early to middle Burdigalian) in age (Figure 19). The age determination is based on correlation with the Marks Head Formation by molluskan faunal zones and the occurrence of two vertebrate faunas (Huddlestun, in press).

The Torreya Formation correlates with the Marks Head Formation of northeast Florida and southeast Georgia. It also correlates with the upper part of the Arcadia Formation of southern Florida (Figure 19). Northward into North Carolina the Torreya equates with the lower Pungo River Formation based on relative ages.

Discussion

It is obvious from this discussion that future investigations, as more data become available, may allow the Torreya Formation of the Hawthorn Group to be further subdivided or revised.

DOGTOWN MEMBER OF THE TORREYA FORMATION

Definition and Type Locality

The Dogtown Member of the Torreya Formation was suggested by Huddlestun and Hunter (1982) for the clay-rich interval in the upper Torreya in parts of Liberty, Gadsden and Leon Counties, Florida, and Decatur County, Georgia. Commercial fuller's earth deposits occur within the Dogtown Member.

The type locality of the Dogtown Member is the La Camelia Mine of Engelhard Corp., located in Section 15, Township 3 North, Range 3 West, Gadsden County, Florida. The Owenby #1 core (W-7472) located in SE ¼, Section 4, Township 2 North, Range 3 West is suggested here as a reference section (Figure 60).

Lithology

The Dogtown Member, as described by Huddlestun and Hunter (1982), and Huddlestun (in press) consists largely of clay. The clays are often quartz sandy, silty and occasionally dolomitic (Weaver and Beck, 1977). The commercial clay beds are quite pure clay but these do not make up the entire unit. Induration is generally moderate. The color of the unweathered, freshly exposed sediment varies from very light gray (N 8) to pale greenish-yellowish (10 Y 8/2) and light bluish-gray (5 B 7/1). Bedding in the clays ranges from thinly bedded (laminated) and somewhat fissile to massive, blocky, poorly bedded units. Where the clay is shaley, there is often silt or fine sand along bedding planes (Huddlestun and Hunter, 1982). The clay beds often contain clay intraclasts and show desiccation cracks (Weaver and Beck, 1977).

Associated with the clay beds are sand and carbonate beds which often separate the clay zone into two beds. The sands are very fine to fine grained, variably clayey, dolomitic or calcareous and poorly to moderately indurated. Colors range from light gray (N 7) to yellowish-gray (5 Y 7/2). The carbonate beds are clayey, sandy, dolostones to limestones with varying percentages of phosphate. Induration varies from poor to good. Colors range from white (N 9) to light olive-gray (5 Y 6/1). Mollusk molds are common in this unit.

The clay minerals associated with the Dogtown Member are predominantly palygorskite and smectite with minor but variable percentages of illite and sepiolite (Weaver and Beck, 1977). The relative percentages of individual clay minerals vary from bed to bed in the section. Lithologically, the Dogtown Member grades vertically both upward and downward into undifferentiated Torreya Formation.

Subjacent and Suprajacent Units

At this time, utilizing limited core and outcrop data, it is difficult to accurately determine the relationship of the Dogtown Member to the Sopchoppy Member. It appears that, although the Dogtown is not known to directly overlie the Sopchoppy Member in any core or outcrop, the Dogtown Member is younger than the Sopchoppy and could possibly be found in a suprajacent position to it. The Dogtown Member is unconformably overlain by the Citronelle and/or the Miccosukee Formations where the contact has been observed.

Thickness and Areal Extent

The thickness of the Dogtown varies from a maximum recognized thickness of 40.5 feet (12 meters) W-7539 (Suber #1) to a minimum of 15.5 feet (4.7 meters) (Huddlestun, in press).

The Dogtown Member occurs in northern Liberty, northern Gadsden, and northern Leon Counties in Florida and in southern Decatur and Grady Counties, Georgia. Its limits in Georgia have not been accurately defined (Huddlestun, in press).

Age

As discussed under the Torreya Formation, the Dogtown is middle Early Miocene (early to middle Burdigalian) in age. It is included in the *Carolia floridana* Zone of Hunter and Huddlestun (1982). Weaver and Beck (1977) also suggested an Early Miocene age for the fuller's earth beds (Dogtown Member).

Discussion

The Dogtown Member of the Torreya Formation contains economically important fuller's earth clay deposits. Although its areal extent has not been accurately defined, it appears to be mappable in a limited area. As is the case with the Torreya Formation in general, more core data are needed to further define the Dogtown Member.

SOPCHOPPY MEMBER OF THE TORREYA FORMATION

Definition and type Locality

Huddlestun and Hunter (1982) suggested using the "Sopchoppy limestone" of Dall and Harris (1892) as a member of the Torreya Formation. The type locality of the Sopchoppy Member is an exposure of fossiliferous, sandy limstone under a bridge over Mill Creek in the center of Section 34, Township 4 South, Range 3 West, northwest of Sopchoppy, Wakulla County, Florida. No core data is presently available in this area.

Lithology

Dall and Harris (1892) refered to the Sopchoppy Limestone as a very soft limestone with numerous imprints of fossils. In referring the Sopchoppy to the Alum Bluff Formation, Matson and Clapp (1909) did not provide descriptions of the limestone.

Huddlestun (in press) recognizes two lithofacies in the Sopchoppy Member: 1) a sandy, fossiliferous limestone, and 2) a tough, phosphatic, dolomitic sand.

The limestone is moldic, fossiliferous, variably sandy and phosphatic and is coarsely bioclastic with a calcareous mud matrix (Huddlestun, in press). The sand facies is a fine grained, well sorted, dolomitic, phosphatic quartz sand. This sand is often irregularly distributed through the limestone unit. Clays are present as interstitial material and include palygorskite and smectite (Weaver and Beck, 1977).

Subjacent and Suprajacent Units

Thickness and Areal Extent

The only recognized occurrence of the Sopchoppy Member is near the Sopchoppy River in Wakulla County, Florida. Its relationship with the overlying and underlying units, and its thickness and extent are not clearly understood (Huddlestun and Hunter, 1982). However, it appears to grade vertically downward into undifferentiated Torreya Formation. In the type area, the Sopchoppy Member is overlain by undifferentiated sands (Pleistocene?).

Age and Correlation

The age of the Sopchoppy Member is based on macrofaunal similarities with the main portion of the Torreya Formation (Huddlestun, in press). This suggests an Early Miocene age.

Correlations of the Sopchoppy with other units are not well understood at this time. Huddlestun (in press) suggests that it may correlate with the phosphatic sands below the Dogtown Member north of the Sopchoppy Member's type area.

Discussion

Very little is known about the Sopchoppy Member of the Torreya Formation outside of its type area. No core data are presently available to study the extent of the unit. Further study is required to better understand the Sopchoppy.

HAWTHORN GROUP MINERALOGY

The sediments here included in the Hawthorn Group have been of interest for many years due in part to their unusual mineralogy and complex lithostratigraphy. While the Hawthorn contains a variety of common minerals, it also has a number of unusual minerals which developed under special conditions. The genesis of these minerals was related to oceanic chemistry, depositional environments and the effects of post-depositional, diagenetic changes.

The unusual minerals present in the Hawthorn Group include francolite, palygorskite, sepiolite, and dolomite. The phosphates have been the focus of much research due to their economic importance. Development of the phosphate minerals and phosphorite deposits required an unusual set of circumstances that also resulted in the formation and deposition of palygorskite and sepiolite. Related to these conditions is the formation of dolomite in the Hawthorn sediments.

Each of these minerals will be discussed separately to contribute to an understanding of the conditions necessary for their formation. The separate discussions show that similar environmental conditions were responsible for the unusual mineral suite commonly recognized in the Hawthorn sediments.

PHOSPHATE

Occurrence in the Hawthorn Group

Phosphate is present in much of the Hawthorn Group, constituting one of the primary lithologic factors for assigning sediments to the group. In peninsular Florida, phosphate is virtually ubiquitous throughout the Hawthorn sediments. Nonphosphatic lithologies are not common but do occur, usually in the more pure clays and carbonates or as rare, clean, quartz sand beds. However, in the eastern Florida panhandle on the northwest flank of the Ocala Platform (Figures 4, 63 and 64), non-phosphatic sediments in the Hawthorn are quite common.

In the Hawthorn sediments statewide, phospate typically occurs as sand-sized grains disseminated throughout the sediment. Pebble-sized phosphate grains are also common but generally are limited (i.e. Bone Valley Member) to localized areas or very thin zones. The concentration of phosphate within the Hawthorn sediments ranges from zero to greater than 50 percent. Characteristically, however, the average concentration in the Hawthorn sediments is between 2 and 10 percent.

Economically important occurrences of phosphate are known in several areas of the state (Figure 65). The most productive deposit is found in the Central Florida Phosphate District in Polk, Hillsborough, Manatee and Hardee Counties. In this district, the phosphate is produced predominantly from the Bone Valley Member of the Peace River Formation with some production occurring from the undifferentiated Peace River Formation. Pebble phosphorites predominate in the Bone Valley Member while sand-sized phosphorites dominate the undifferentiated section. Southward into the southern extension of the Central Florida Phosphate District (Hardee, Manatee, Sarasota and DeSoto Counties), the production comes from the undifferentiated Peace River Formation.

The southeast Florida phosphate deposit, located primarily in Brevard and Osceola Counties (Figure 65) contains phosphorite in the undifferentiated Peace River Formation. This deposit occurs on the flank of the Brevard Platform (Figure 4). There has been no mining in the southeast Florida deposit.

Phosphate production in north Florida is limited to an area in eastern Hamilton County. The Northern Florida deposit extends eastward and southward as shown in Figure 65. Production in north Florida is from the Statenville Formation. This deposit is located on the northeast flank of the Ocala Platform (Figures 4 and 65). The northern Florida deposit is associated with the lower grade south Georgia deposit (Figure 65).

Further east in north Florida is the northeast Florida deposit (Riggs, 1984) (Figure 65). This deposit is unique in that it is much deeper in the section, occurring more than 200 feet (61 meters) below land surface. These sediments are tentatively placed in the Marks Head Formation of the Hawthorn Group based on very limited core data. If the formational assignment is correct, the phosphorites may represent the oldest Miocene phosphorite deposit in the southeastern United States. Currently, experimental borehole mining techniques are being used to test the feasibility of mining this deposit (Scott, L.E., 1981).

One other important phosphate deposit, the Hard Rock Phosphate District, occurs in northern Florida. It is not currently considered part of the Hawthorn Group although weathering of the Hawthorn Group sediments was probably responsible for the formation of the hard rock phosphates. The Hard Rock District lies west of the present erosional scarp of the Hawthorn Group and occurs on the eastern flank of the Ocala Platform (Figures 4 and 65). Currently the hard rock deposits are not being mined.

Phosphate Genesis

The abundance of phosphate in the Hawthorn sediments is anomalous when compared to the remainder of the Tertiary sediments. Many questions arise concerning the genesis of phosphate in Florida including: 1) What was the source of the phosphate?; 2) How was it deposited?; 3) What role did topographic or structural features play? Research worldwide is producing a greater insight into the processes involved in the formation of marine phosphates. However, the problem is still far from being thoroughly understood.

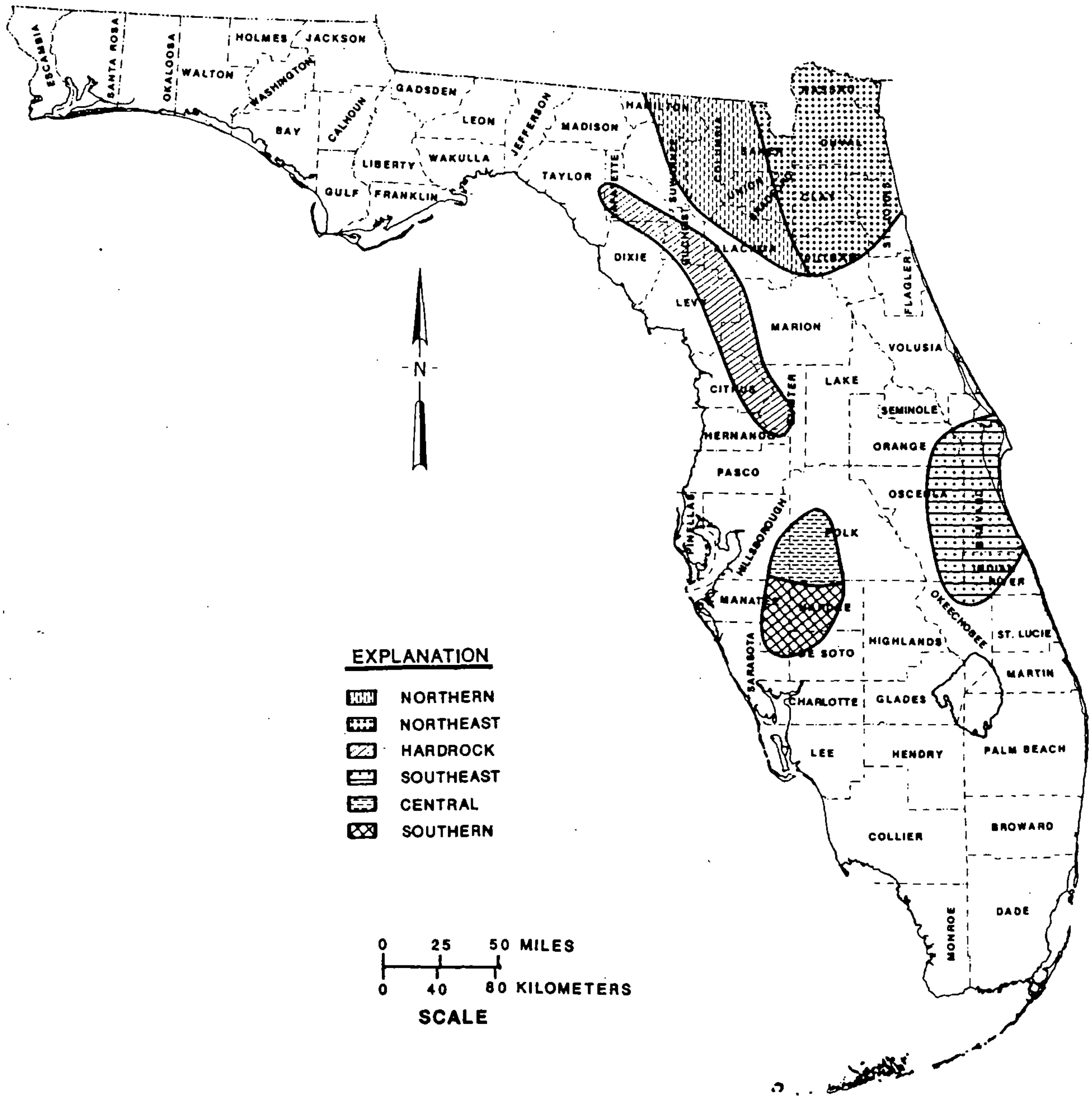


Figure 65. Location of phosphate deposits in Florida.

The phosphorite deposits in the southeastern United States are enigmatic when compared to other occurences of marine phosphorites in the world (Riggs, 1984). Most marine phosphorite deposits occur on western continental shelves where upwelling is associated with trade wind belts, or along east-west seaways characterized by equatorial upwelling. The southeastern United States deposits do not fall into these categories. More recent research indicates, however, that similar mechanisms (upwelling and currents) may be involved in the phosphorite formation in the southeast (Riggs, 1984).

Kazakov (1937) originally suggested that marine phosphorites were precipitated inorganically from upwelling, cold, phosphorus-rich water. The inorganic mechanism for phosphorite precipitation has been suggested to be unlikely by more recent research (Bentor, 1980).

Upwelling, however, remains an important mechanism in the formation of these deposits. Upwelling currents provide the nutrients necessary for the production of large amounts of organic matter (Sheldon, 1980). Subsequent concentration of the phosphorus may result from the action of bacteria at or above the sediment-water interface (Riggs, 1979b), or in interstitial pores within the sediment (Burnett, 1977).

An oceanographic event of global extent was responsible for the formation of the Miocene phosphorite deposits in the southeastern United States (Riggs, 1984). The deposition of the phosphorites and associated phosphatic sediments was controlled by the regional structural framework and the effects of the impinging upwelling currents (Riggs, 1984). Figure 66 shows the structural features of the southeastern coastal plain from North Carolina to Florida that probably controlled phosphate deposition. Only Florida's structural framework will be discussed here.

The dominant positive structural features in the peninsula are the Ocala Platform and the Sanford High including the Sanford High's northern and southern extensions, the St. Johns Platform and the Brevard Platform, respectively (Figure 66). The negative features include the Jacksonville Basin and the Osceola Low. These structures are all considered as pre-Miocene features (Vernon, 1951). Riggs (1979b) considered the structural framework to be one of the most important variables in the development of the phosphogenic system. He outlined three criteria for the development of the phosphogenic system. First is the appropriate regional setting which defines the limits of the system. Second, shoaling environments associated with structural or topographic highs and adjacent basins must occur. Third, the highs must have the appropriate topography to produce the phosphorite and accumulate it in associated topographic lows. Florida's regional structural setting meets these criteria.

According to Riggs (1984), optimum production of phosphate occurred on the flanks of the highs in Florida while significantly less formed elsewhere in the marine environment. Gulf Stream-associated upwellings resulting from bathymetric (topographic) influences impinged on the flanks of the structures providing the necessary constant supply of phosphorus required for phosphate deposition. Miller (1982) suggested that the upwellings associated with north Florida phosphate deposition were related to a south-flowing cold-water current that Gibson (1967) identified during a faunal study of the phosphorites in North Carolina. Hoenstine (1984) also recognized a cold water diatom flora in portions of the Hawthorn Group in an investigation of the group in northeast Florida.

Riggs (1979b) believed that phosphate deposition occurred as a biochemically precipitated mud in the shallow water environments on the positive structural features. The microcrystalline phosphate mud (microsphorite) is not commonly preserved; however, remnants of the microsphorite beds may be present in the Hawthorn Group sediments. Many of the zones suggested to be microsphorite appear to be 1) phosphatized carbonate hard grounds; 2) phosphatic subaerial crusts; and 3) secondary deposits of phosphate by groundwater. The microsphorite beds were reworked into pelletal and intraclastic grains that were deposited in topographic lows on the flanks of the positive features. Riggs (1979a) suggested that many of the pelletal grains originated from the ingestion of phosphate mud by organisms and the excretion of phosphatic fecal pellets. Miller (1982) suggests that gentle currents were responsible for the formation of the pelletal phosphorites in north Florida. Intraclastic and lithoclastic fragments could have resulted from the erosion and reworking of semilithified to lithified microsphorite beds and possibly phosphatized carbonate beds.

Burnett (1977) suggested that the phosphorites forming off the coast of Peru and Chile are inorganically precipipated in the pore waters of anoxic sediments. Phosphorus-rich waters upwell onto the shelf pro-

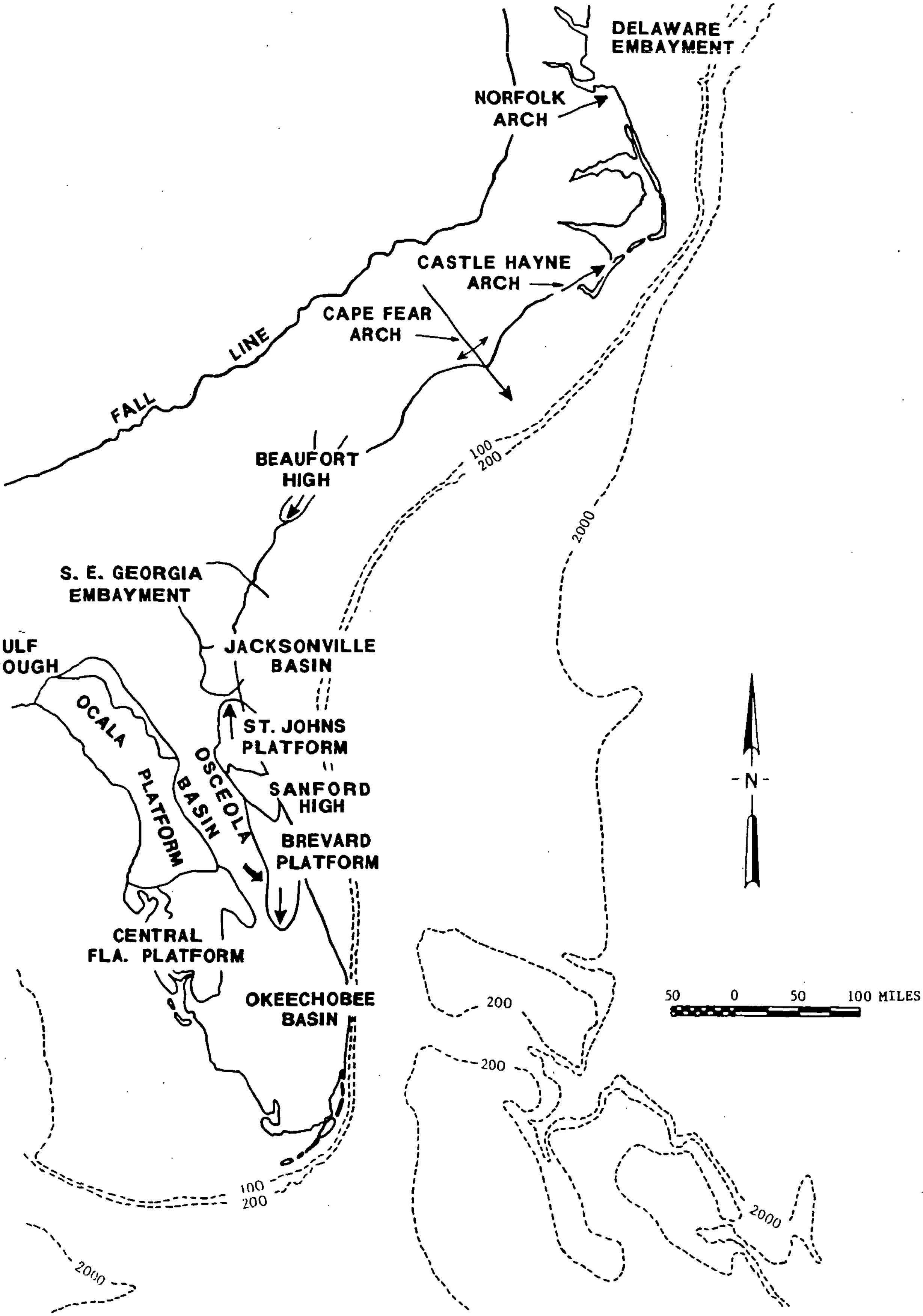


Figure 66. Structural features of the southeast United States (after Riggs, 1979).

viding the necessary nutrients for high biologic productivity resulting in an increased accumulation of organic material in the bottom sediments. Burnett et al. (1980) indicated that the highest concentration of phosphate in the sediments occurred in the zone of oxygen minimum. The phosphate is provided to the pore waters by the decomposition of the incorporated organic matter. The precipitation of phosphate in the pores results in the growth of nodules and, presumably, various sizes of pellets in the sediment.

The resultant phosphate grains range from silt-sized to pebble-sized with the size range becoming coarser and identifiable intraclastic fragments becoming more common toward the phosphate source area. Riggs (1979b) has noted this occurrence on the flanks of the Ocala Platform. Away from the areas of primary phosphate deposition, the percentage of phosphate present in the Hawthorn sediments generally decreases as does the ratio of pebble to sand-sized phosphate.

Riggs (1979b) suggested that, away from the highs or positive structural features, fine sand-sized and silt-sized phosphates formed from a loose colloidal suspension of orthochemical phosphate occurring above the bottom. As the aggregates formed they trapped other sediments in them including silts, dolomite rhombs, organic debris and clays. The resulting aggregates were subsequently incorporated in the bottom sediments.

It is the author's opinion that the vast majority of phosphate grains in Florida have been transported, or at least reworked, from their original depositional area. Throughout the Hawthorn Group, the occurrence of phosphate appears related to the occurrence of quartz sand. It is uncommon for the percentage of phosphate to exceed the percentage of quartz sand in a clay or carbonate sediment except in the case of a phosphorite such as those currently being mined. The lack of phosphate grains in relatively pure carbonates (lacking quartz sand or other siliciclastic particles) in the Hawthorn is very common even though these units may be overlain and/or underlain by quartz sandy carbonates containing phosphate. The same relationship applies to relatively pure clays and sandy clays. These relationships suggest that, although phosphate in Florida is a precipitate, it most often becomes a clastic particle which is subsequently deposited at varying distances from the source areas. Phosphorite deposits result when sufficient quantities of phosphate are available and wave and/or current energies are sufficient to winnow and concentrate the phosphate grains. Sedimentary features, including graded bedding and cross bedding, are indicative of the higher energy conditions present during phosphorite deposition. Grain size and shape of the phosphate particles may also be indicative of reworked materials, since the grains vary from rounded and sand-sized to subangular or rounded and pebble-sized.

Post-Depositional Modification

Post-depositional weathering and reworking of the Hawthorn sediments have been relatively widespread. The best documented effects are those that affect the sediments of the major phosphorite deposits. Leaching, redeposition and reworking have all played a role in the modification of the original phosphatic material in the Hawthorn sediments.

Throughout much of northern and central Florida, part of the Hawthorn Group (Figure 5) has been subjected to the effects of groundwater migration. Leaching of the soluble phosphates has been one of the major effects of this process, resulting in the total loss of phosphate in extreme cases. The post-depositional development of the "leached zone" in the Central Florida phosphorite deposits has been discussed by a number of authors including Altschuler and Young (1960), Altschuler et al. (1964), Riggs (1979a) and Hall (1983).

Supergene weathering of the phosphorite tends to upgrade or increase the phosphate content by removing the included carbonates and organic material. The deveopment of the aluminum phosphate zone is the direct result of weathering of the carbonate fluorapatites. Riggs (1979a) recognized seven zones ranging from unaltered to completely leached. These zones were gradational and all zones may not be fully developed in any one section. The typical zonation trends from: unaltered carbonate fluorapatite to mixed calcium-aluminum phosphates to aluminum phosphates and, finally, to phosphate free. As the phosphate grains are leached the color changes from shiny black and dark brown to earthy-textured light colors and white. This same process of supergene weathering alters and removes clays as well. The net

result is the development of a clean quartz sand which constitutes part of the overburden (Altschuler and Young, 1960).

Elsewhere in the state, where the upper Hawthorn sediments do not constitute an economic phosphorite deposit, weathering follows a similar sequence but without the extensive development of the aluminum phosphate zone. As the phosphate and carbonate are removed, a vesicular sandstone develops.

Hard Rock Phosphate Deposits

Hard rock phosphate deposits are found scattered along the eastern flank of the Ocala Platform west of the present limits of the Hawthorn Group (Figure 65). Cooke (1945), Vernon (1951) and Puri and Vernon (1964) considered these deposits as part of the Alachua Formation. The phosphate occurs as "plates or large boulder like masses" (Cooke, 1945) resting on the surface of the underlying limestones of the Ocala Group or Suwannee Limestone. Cooke (1945) also reported that the phosphate has replaced portions of this underlying carbonate. These deposits were mined from 1890 until the mid-1960s, when the last operation closed.

The origin of the hard rock phosphate is intimately related to the development or occurrence of a phosphorite deposit in the Hawthorn Group. Sellards (1913) believed that the phosphate was derived from overlying phosphatic sediments by dissolution and was subsequently reprecipitated to form the hard rock deposits. Cooke (1945) also supported this theory. Sellards (1913) discussed theories proposed by other authors, many of whom felt the source of the phosphate to be guano. Vernon (1951) believed guano to be the source of the phosphate, citing the fact that he did not believe the phosphatic materials of the Hawthorn Group were deposited that high on the Ocala Platform.

The Hawthorn Group was postulated to have extended over much of the Ocala Platform (Scott, T.M., 1981) based on the occurrence of cherts in the upper part of the Ocala Group and Suwannee Limestone. The occurrence of phosphatic sands associated with the hard rock phosphates also suggests the former presence of the Hawthorn Group in the Hard Rock Phosphate District.

Based on these assumptions, the present author agrees with Sellards (1913), Cooke (1945) and Upchurch and Lawrence (1984) that phosphates present in the Hawthorn Group on the east flank of the Ocala Platform were probably the source of the phosphorus which developed the hard rock phosphate deposits. It is suggested here that the original Hawthorn phosphorite deposit formed in the manner described for other Florida deposits. It then underwent extensive leaching, erosion and reworking to develop the hard rock phosphates and the residual Hawthorn sediments previously placed in the Alachua Formation. It is interesting to note here that recent research on the erosional scarp of the Hawthorn Group in Columbia County indicates that groundwater in the Floridan aquifer system under the Hawthorn Group near the scarp is supersaturated with respect to PO_4 (Upchurch and Lawrence, 1984). Upchurch and Lawrence believe that the development of karst features penetrating the Hawthorn sediments allows the phosphorus-bearing water to enter the aquifer system. They also feel that this mechanism may have allowed the development of the hard rock deposits and may explain the discontinuous nature of their occurrence.

PALYGORSKITE AND SEPIOLITE

Palygorskite and sepiolite are not generally considered common clay minerals. Their sedimentary origin is not well known, although it is generally assumed that restricted conditions are often required for their formation. Their occurrence in the Hawthorn Group of the Florida, Georgia and South Carolina coastal plain, where they often are the dominant clay mineral, is well documented (Reynolds, 1962; Heron and Johnson, 1966; Weaver and Beck, 1977; Reik, 1982; Hetrick and Friddell, 1984). The occurrence of these clays in association with dolosilts and phosphate indicates unusual depositional environments for the Miocene sediments in the southeastern United States.

Palygorskite and sepiolite are magnesium silicate clay minerals belonging to the 2:1 layer group and possessing an amphibole-like chain or fibrous structure. While the two minerals differ slightly in structure, they have very similar chemical formulas. The major difference is that palygorskite contains some aluminum substituted for magnesium while sepiolite does not (Hathaway, 1979). For a complete discussion of the mineralogy and chemistry of palygorskite, see Gremillion (1965), Grim (1968), Weaver and Beck (1977), Ogden (1978), and Hathaway (1979).

Palygorskite and sepiolite occur throughout the Hawthorn Group mixed with variable proportions of smectite, illite, chlorite and some kaolinite. Hetrick and Friddell's (1984) study of the Hawthorn Group clay mineralogy indicated a highly variable clay-mineral composition that is not obviously related to stratigraphic position. However, statistical evaluation of this data indicated that the formations of the Hawthorn Group are significantly different from each other in smectite, palygorskite and sepiolite content (Hetrick and Friddell, 1984). They indicate that palygorskite and sepiolite are the dominant clay minerals in the Marks Head Formation of northern Florida and Georgia, while smectite dominates in the Coosawhatchie and Penney Farms (Parachucla) formations.

Palygorskite and sepiolite are often closely associated with dolomitic sediments (Reynolds, 1962; Weaver and Beck, 1977; Reik, 1982). The dolomite in these sediments is commonly the limpid dolosilt discussed in the dolomite section of this paper.

The modes of formation and depositional environments of palygorskite and sepiolite have been studied by a number of authors (McClellan, 1964; Gremillion, 1965; Millot, 1970; Weaver and Beck, 1977; Ogden, 1978; Strom and Upchurch, 1985) resulting in a number of depositional models. The formation of these clays has been postulated to have resulted from: 1) weathering (Kerr, 1937), 2) alteration of volcanic ash (Gremillion, 1965), 3) transformation from clay mineral precursor (Weaver and Beck 1977, Ogden, 1978), and 4) neoformation or precipitation from sea water (Millot, 1970). Currently, the transformation of a clay mineral precursor such as montmorillionite by the addition of silicon and magnesium is the accepted mode of formation for palygorskite and sepiolite. It should be noted here that a minor amount of palygorskite probably precipitated directly from solution (Weaver and Beck, 1982).

The development of palygorskite and sepiolite was thought to occur primarily in restricted, brackish water (schizohaline) lagoons and tidal flats by Weaver and Beck (1977, 1982) and Ogden (1978). Weaver and Beck (1977) suggest that sepiolite formed under more fresh water conditions in this environment. The transformation of the precursor clay minerals to palygorskite and sepiolite requires a relatively high pH (8-9) as suggested by Weaver and Beck (1977), and a supply of silicon and magnesium. The pH increases in response to evaporation in the restricted environments, and, perhaps seasonally, reaches the required high pH levels. As the pH levels increase, the solubility of biogenic opal (found in diatoms and siliceous sponge spicules) increases, supplying the silicon required. Magnesium is concentrated due to the evaporation of the brackish waters. Given these conditions, and a supply of a suitable precursor clay mineral such as smectite, Weaver and Beck (1977) and Ogden (1978) postulate the development of palygorskite and sepiolite clays.

Weaver and Beck (1977) also discuss the development of limpid dolomite in association with palygorskite genesis. They suggest that dolomite forms both prior to palygorskite formation and after it. This may also indicate a seasonality to the critical nature of the depositional environments.

Restricted, alkaline lagoons probably occurred over a wide area during Hawthorn deposition. The flanks of the Ocala Platform possibly provided ideal environments for palygorskite formation as did parts of the St. Johns and Brevard Platforms and the Sanford High. The reworking of these palygorskite-rich deposits during transgression could provide vast amounts of clay that could be incorporated in the more normal marine portions of the Hawthorn Group downdip. The association of dolomite in both the environment of the reworked palygorskite indicates the possibility that the silt-sized dolomites were transported into depositional basins.

Upchurch et al. (1982) and Strom and Upchurch (1983) discuss the development of palygorskite and opaline chert in perimarine, alkaline-lake environments. Their discussion of the palygorskite and opal-forming environments suggests a somewhat more restricted environment than that discussed by other authors. It seems to this author that the more restricted environment of Upchurch, et al. (1982) may have occurred in conjunction with less restricted, palygorskite-producing, brackish water (alkaline) lagoons. However, the ephemeral lakes of these authors were less common and of smaller areal extent than the

lagoonal environments. The net result is the large scale production of palygorskite with a more limited creation of opaline sediments and subsequent reworking of the palygorskite into the depositional basins.

DOLOMITE

Dolomite, like phosphate, is a rather enigmatic mineral in nature. A number of different types of dolomite are known to exist, suggesting that there is not a single, unique process by which dolomite forms or dolomitization occurs. As a result, there is no unique model to explain dolomite genesis (Zenger and Dunham, 1980). It is important to attempt to understand the occurrence of dolomite in the Hawthorn Group, due to the association of dolomite with phosphate and palygorskite. The knowledge resulting from attempts to determine the origin of one mineral may shed light on the origin of the other minerals.

Carbonate rocks dominate the Hawthorn sediments in a large portion of southern Florida. Northward, the carbonate content decreases as the terrigenous component increases. Even in the northern area, however, carbonate remains an important constituent, both as a primary lithology and as an accessory mineral.

Dolomite is the most common carbonate component in the Hawthorn Group throughout much of the state. Only in portions of southern Florida does dolomite assume a subordinate position with respect to limestone in the group. Dolomite occurs in several different modes; the predominant types are dolomitized limestones or secondary dolomites and dolosilts. It also is present as an accessory mineral in clays, clayey sands, limestones and many phosphate grains.

Secondary dolomites are present in the carbonates of the Hawthorn Group throughout the state. These dolomites are characterized by a coarse, anhedral dolomite replacing the original limestone. Most original depositional features are destroyed by the dolomitization, although ghost structures of pellets and fossils have been observed in thin section. Molds of mollusk shells are common and are often lined with later-phase dolomite and/or sparry calcite druses. It appears that the original carbonate rock was a wackestone to a mudstone that contained a variable siliciclastic component, including phosphate. This type of dolomite is most common in the basal Hawthorn Group Penney Farms Formation in northern Florida.

The dolomites of the basal Hawthorn Group in much of northern and part of southern Florida lie directly on undolomitized Eocene (Oligocene in a few cases) limestones. The development of the dolomite was restricted to the Miocene carbonates by some mechanism. The occurrence of a recrystallized low permeability zone in the upper few feet of the undolomitized limestones below the pre-Hawthorn unconformity may have provided enough of a permeability barrier to groundwater movement to limit dolomitization to the Miocene carbonates. Further study is required to determine if the dolomitization is an early or later diagenetic event.

Dolosilt is a term applied to unconsolidated, silt-sized, euhedral, rhombic, often limpid crystals of dolomite. This type of dolomite has also been referred to as microsucrosic dolomite when more lithified (Prasad, 1983). Dolosilts are extremely common in the sediments of the Hawthorn Group ranging from a minor accessory mineral to a nearly pure dolosilt sediment. The dolosilts range from fine silt-sized (10 microns) to fine sand-sized (greater than 62 microns). The individual crystals show sharp crystal faces and often have hollow centers.

Lithologically, dolosilts are present in a wide variety of sediment types. Clays and clayey sands of the Hawthorn Group very commonly contain dolosilts in widely varying amounts. A complete gradation between the clays and dolosilt-rich sediments often occurs, causing some problems in identifying the components of the sediment, since minor amounts of clay in a fine-grained dolosilt may present the appearance of a siliciclastic, silty clay lithology.

The carbonate portions of the Hawthorn Group contain variable percentages of dolosilt. Beds vary lithologically from nearly pure dolosilt and dolostone to limestones with minor percentages of dolosilt floating in a carbonate mud matrix. Prasad (1983) has identified two types of dolomite in the Hawthorn of southern Florida. First, he recognized a dolomite fraction of microsucrosic, silt-sized rhombs (dolosilts) that show no replacement textures. Second, Prasad identified fine grained dolomite associated with dolosilts that exhibited a replacement texture. The dolomite replaced metastable fossil fragments often

with a syntaxial dolomite rim (Prasad, 1983). Prasad also noted that there is an inverse relationship between micrite and dolosilt in the carbonate beds suggesting a replacement of the micrite by dolosilt.

In northern parts of central Florida, dolosilts are significantly more abundant than in south Florida. This suggests that dolomite genesis (and perhaps dolomitization) was more intense or complete in these areas than in the southern area discussed by Prasad (1983). It is also interesting to note that the northern and central Florida dolomites are associated with greater amounts of palygorskite and, in general, phosphate.

Silt-sized dolomite rhombs and occasionally clasts of dolomite are often incorporated in phosphate grains. Riggs (1979a) states that it is not unusual if as much as 90 percent of the phosphate grains in a deposit contain inclusions of dolomite. This association is important since the two mineral phases do not form in the same geochemical environment. The magnesium concentration is a controlling factor in the development of phosphate in that magnesium inhibits the formation of phosphate in normal seawater (Bentor, 1980). Riggs (1979a) recognizes evidence of transportation of the dolomite rhombs. He suggests that the dolomite and phosphate developed in adjacent areas and that the dolomite was transported then mixed with the phosphate muds.

The origin of dolomite is a confusing and enigmatic question. Even though it is a common rock-forming mineral and an accessory mineral, the various modes of formation are not well understood. With respect to the dolomites in the Hawthorn Group, there appears to have been several types of dolomite development. These types include replacement of limestones (secondary dolomite), dolomitization of metastable fossil material, and dissolution of aragonite and high-Mg calcite mud with co-precipitation of dolomite (dolosilt or microsucrosic dolomite).

The replacement of limestone by dolomite is virtually complete in the carbonates of the Hawthorn Group's Penney Farms and Marks Head Formations in northern Florida. Dolomitization on this broad scale is suggestive of a mixing zone mode of formation for the dolomites. As described by Badiozamani (1973), dolomite may be formed by the replacement of limestone by groundwaters of mixed fresh and marine origins. It is suggested here that these dolomites in the Hawthorn Group resulted from the migration of mixed-water zones through the carbonate sediments as sea levels fluctuated during the Late Miocene. The timing of this event is purely speculative based on proposed sea level curves (Vail and Mitchum, 1979). Further research is needed to fully understand the timing and mode of formation of the replacement dolomites.

Dolosilts, or microsucrosic dolomites, may also form from the effects of mixing-zone waters on fine grained carbonate sediments and fossil debris. Prasad (1983, 1985) studied the microsucrosic dolomites of the Arcadia and Peace River Formations in southern Florida. He concluded that dolomitization of the metastable fossil material (echinoderm plates) occurred prior to freshwater diagenesis. The dolosilts appear to have precipitated from dilute solution in the interstital pores. The source for the calcium carbonate to form the dolomite in the mixed waters is inferred to have come from dissolution of fine grained lime mud (Prasad, 1983, 1985). The fine grained, limpid, euhedral, rhombic nature of the dolosilts is considered indicative of growth from dilute solutions in mixed waters (Folk and Land, 1975). Based on the belief that these dolomite crystals form in a brackish water environment, Weaver and Beck (1977) believed that the dolosilts formed in the same environment as the palygorskites.

Very small (1 micron), well-formed, rhombic dolomite crystals have been recognized cementing aragonitic muds on portions of Andros Island (Gebelein, et al. 1980). Growth of these dolomite crystals concurrently with dissolution of the aragonite results in limpid, inclusion-free dolosilts. These sediments may form in two ways, both of which are related to mixing of fresh and marine water. First, they may form in an intertidal or tidal flat environment as recognized by Gebelein, et al. (1980). Secondly, they can develop in migrating mixed water zones in buried sediments (very shallow burial in this case) due to sea level fluctuations (Prasad, 1983, 1985). Both origins seem to be represented in the dolosilts of the Hawthorn Group.

GEOLOGIC HISTORY

Sedimentation in peninsular Florida throughout the Paleogene was dominated by carbonate deposi-

tion. Only minor percentages of siliciclastic materials are present in the pre-Miocene sediments. At the beginning of the Neogene, the influx of siliciclastic materials increased dramatically, flooding the carbonate environments and pushing these environments southward. Carbonate deposition continued perhaps as late as early Middle Miocene in parts of south-central Florida to Late Miocene (?) in the Keys. Within the carbonate units, siliciclastic material occurring as both accessory minerals and the dominant sediment type in thin beds generally increased in percentage with decreasing age.

Chen (1965) believed that the Gulf Trough (his Suwannee Channel) (Figure 4) acted as a natural barrier to the southward movement of siliciclastic material until near the end of the Eocene. However, a large influx of siliciclastic material is not recognized until Miocene time. The assumed source for the siliciclastics is the southern Appalachian Mountains and the Piedmont. The reason for the dramatic increase in the supply of siliciclastics has not been documented. However, it is possibly the result of a renewed uplift in the southern Appalachians in the late Paleogene or early Neogene.

The geologic history of the Hawthorn Group is directly related to the Miocene fluctuations of global sea level. An understanding of the global sea levels such as those proposed by Vail and Mitchum (1979) aid in determining the depositional controls exerted by features such as the Sanford High and the Ocala Platform. Since the proposed sea level curves are thought to be free from local tectonic influence, comparison of these curves to the present position of the Hawthorn Group sediment may shed light on the possibilities of tectonic influence on the Florida platform.

Throughout the Tertiary, the Florida platform has been subjected to numerous fluctuations, transgressions and regressions of the sea. The effects of these variations in sea level have been most dramatic from the latest Oligocene through the Pleistocene. Coastal onlap curves published by Vail and Mitchum (1979) reflect these changes along with the apparent relative magnitudes of the fluctuations based on relative coastal onlap (Figure 67).

In contrast to the Vail and Mitchum (1979) sea level curves is the classical idea of fluctuating sea levels expressed by Cooke (1945). According to Cooke (1945), there is a three-fold subdivision of the Miocene present in Florida. Each subdivision was the result of a sea level rise from a previous low stand and a subsequent withdrawal of the sea at the end of each division. The subdivisions were referred to as the Early, Middle and Late Miocene. Cooke (1945) believed that sea level rose to its greatest height during the Middle Miocene.

The relationships of the formations of the Hawthorn Group to the proposed sea level are shown in Figure 67. The formations of the Hawthorn Group in the peninsular area (north and south Florida of Figure 1) are predominantly related to the sea level stands of the earliest Miocene through middle Late Miocene. In the panhandle, Hawthorn Group deposition is thought to be restricted to the Burdigalian as recognized in the Torreya Formation.

Correlations of the Hawthorn Group sediments to the Vail and Mitchum (1979) sea level curve indicate the following sequence of events. The earliest marine transgression that is suggested to have affected the deposition of the Hawthorn Group began in the Early Miocene (Aquitanian). At least part of the Penney Farms Formation was deposited at this time as was the lower portion of the Arcadia Formation (Tampa and Nocatee Members and undifferentiated Arcadia). Deposition was interrupted when the sea level dropped in mid-Early Miocene (Early Burdigalian). As sea level continued to rise through the Early Miocene, Hawthorn deposition resumed. Although it is not yet documented, the upper portion of the Penney Farms Formation may have been deposited during this period. Much of the upper part of the Arcadia Formation was also deposited during this transgression. In the panhandle, the deposition of the Torreya Formation of the Hawthorn Group began during this transgression. However, the documented age for the Torreya Formation is Early to Middle Burdigalian (Huddlestun, in press).

As sea level rose in Late Burdigalian, the Marks Head Formation, the Torreya Formation and the upper portion of the Arcadia Formation were deposited. Sea level continued the rising trend into the Middle Miocene as Marks Head and Torreya deposition ceased. In peninsular Florida the Coosawhatchie was deposited on the Marks Head in northern Florida during the Serravalian. In southern Florida, the Arcadia Formation deposition ended in Serravalian and later Miocene deposition in the panhandle Hawthorn Group has not been recognized. This is due either to non-deposition or erosional removal of these

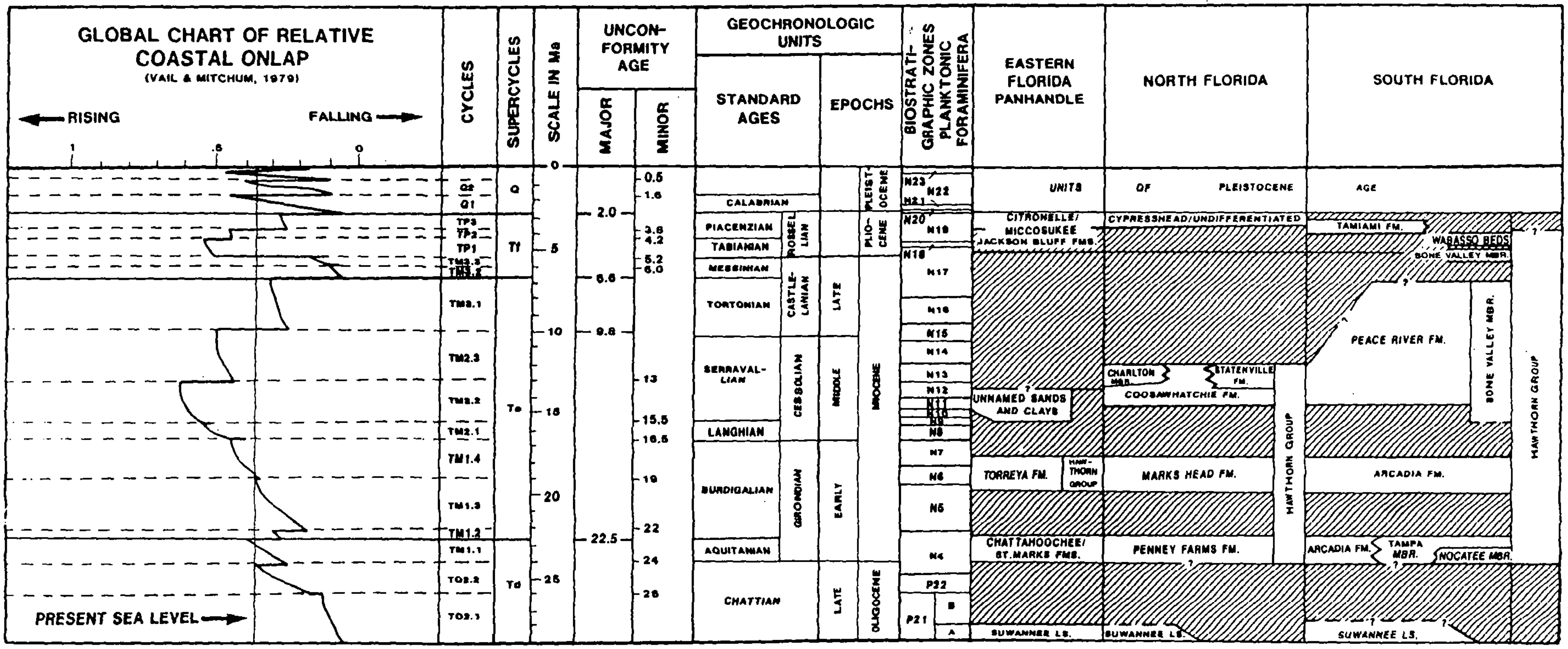


Figure 67. Lithostratigraphic units in relation to proposed sea level fluctuations (after Vail and Mitchum, 1979).

sediments. Post-Serravalian (Tortonian) deposition appears to be limited to southern Florida and perhaps some of the central east coast area where sediments assigned to the Peace River Formation have been identified. Most Hawthorn sedimentation ended by the end of the Tortonian upon the sea level drop of the Messinian. Huddlestun et al. (1982) recognized an informal unit of the Hawthorn Group which was deposited in late Early Pliocene (Tabianian). These beds, referred to as the Indian River beds (later changed to Wabasso beds by Huddlestun (personal communication 1984)) were deposited during the post-Messinian sea level rise. The unit is recognizable only faunally and its extent in Florida is not presently known. During this time the upper bed of the Bone Valley Member of the Peace River Formation developed in part of Polk, Hillsborough, Hardee and Manatee Counties. This bed is the classic Bone Valley Gravel of the earliest usage.

Vail and Mitchum's (1979) sea level curve also lists a number of major and minor unconformities recognized in the seismic sections. Although there are a number of unconformities visually recognizable within the Hawthorn Group (particularly in northern Florida), their correlation with those of Vail and Mitchum (1979) is highly speculative. The difficulty in correlating the unconformities may arise from the very poor biostratigraphic record of the Hawthorn Group in much of Florida or from problems associated with the Vail and Mitchum curve. At this time no attempt is made to correlate the minor unconformities. If future biostratigrahic investigations identify more complete, correlatable faunas or a refinement of Vail and Mitchum's sea level curve occurs, the minor unconformities may be recognized and correlated.

The major unconformities relating to the base of the Hawthorn Group in peninsular Florida are the pre-Hawthorn to post-Ocala unconformity (the Oligocene absent), and the pre-Hawthorn to post-Suwannee unconformity (Latest Oligocene).

Fluctuating sea levels caused varying amounts of land area to be exposed subaerially during the Late Oligocene through Early Pliocene. During the periods of exposure terrestrial vertebrates inhabited the area. The fossil remains found in sinkholes, stream channels and nearshore sediments provide a means of determining the age of the enclosing sediments and therefore the age of the terrestrial episodes.

The series of hypothetical cross sections shown in Figures 68 to 72 suggest a possible geologic history of the Hawthorn Group in Florida. The line of section extends from northern Madison County southeastward to eastern Marion County then south-southeast to Palm Beach County. This series of sections takes into account erosion of sediments during low sea levels and the slow downwarping of southern Florida from a hinge line in Osceola County south. The erosional removal of sediments is shown on the sections as erosional vacuities from several different periods.

The earliest Neogene exposure of the platform occurred during Late Oligocene into Early Miocene (Figure 68). It is very probable that much of the Florida Platform was exposed during this time. Following this low stand, sea level rose but probably did not cover the entire platform. The deposition of the basal Arcadia, the Penney Farms, and the St. Marks Formations occurred during the early Early Miocene. Following this event there was a minor regression then continued transgression. During this period, as the sea levels rose, the Martin-Anthony fauna (MacFadden, 1980) and a terrestrial fauna collected along the Tampa By-Pass Canal (Dale Jackson, personal communications, 1984) were deposited. Both sites contain associated marine fossils indicating a close proximity to land. Upchurch (personal communication, 1986) notes that the Tampa By-Pass Canal exposed some "Tampa" sediments containing a freshwater component to the fauna. These sites are 25 to 22 million years old and are of Arikareean age (North American Land Mammal Age, NALMA) (Chattian and Aquitanian, Figure 73).

Following an earliest Miocene decline in sea level, the sea level began a rise which continued with only minor interruptions through the Early Miocene. Deposition of the upper part of the Arcadia, the Marks Head and the Torreya Formations occurred in the later part of the Early Miocene. During this time (Hemingfordian NALMA; Burdigalian and possibly Aquitanian) a diverse land mammal fauna developed. A number of localities containing this fauna occur in north central and panhandle Florida (see MacFadden and Webb, 1982). The number of sites and their distribution indicate that in the latter part of the Early Miocene, there was a considerable area above sea level (Figure 69). As sea level continued to rise these areas were eventually covered.

Sea level continued to rise reaching its maximum height in the mid-Middle Miocene (Figure 70), when

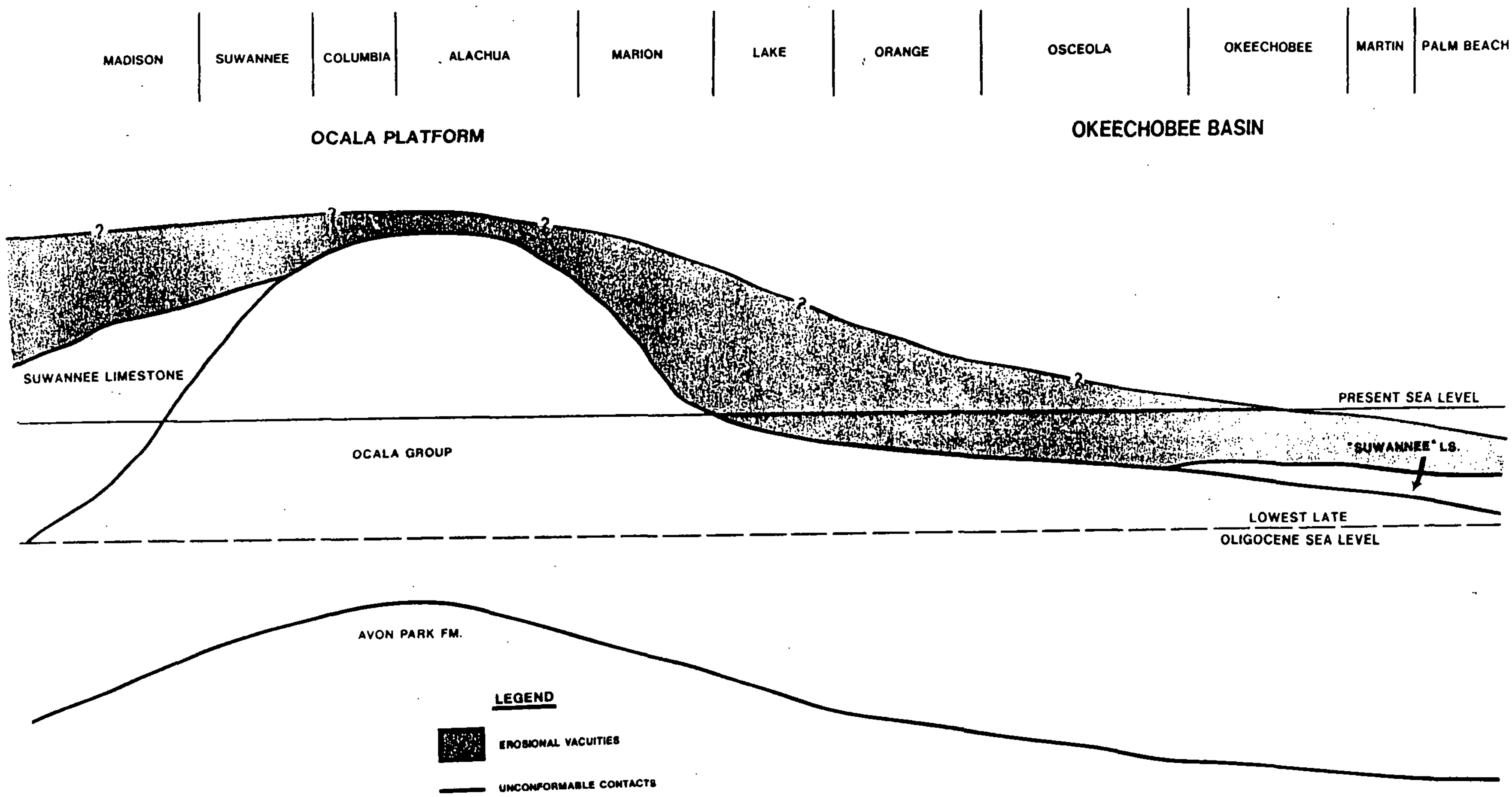


Figure 68. Cross section showing reconstructed stratigraphic sequence at the end of Late Oligocene.

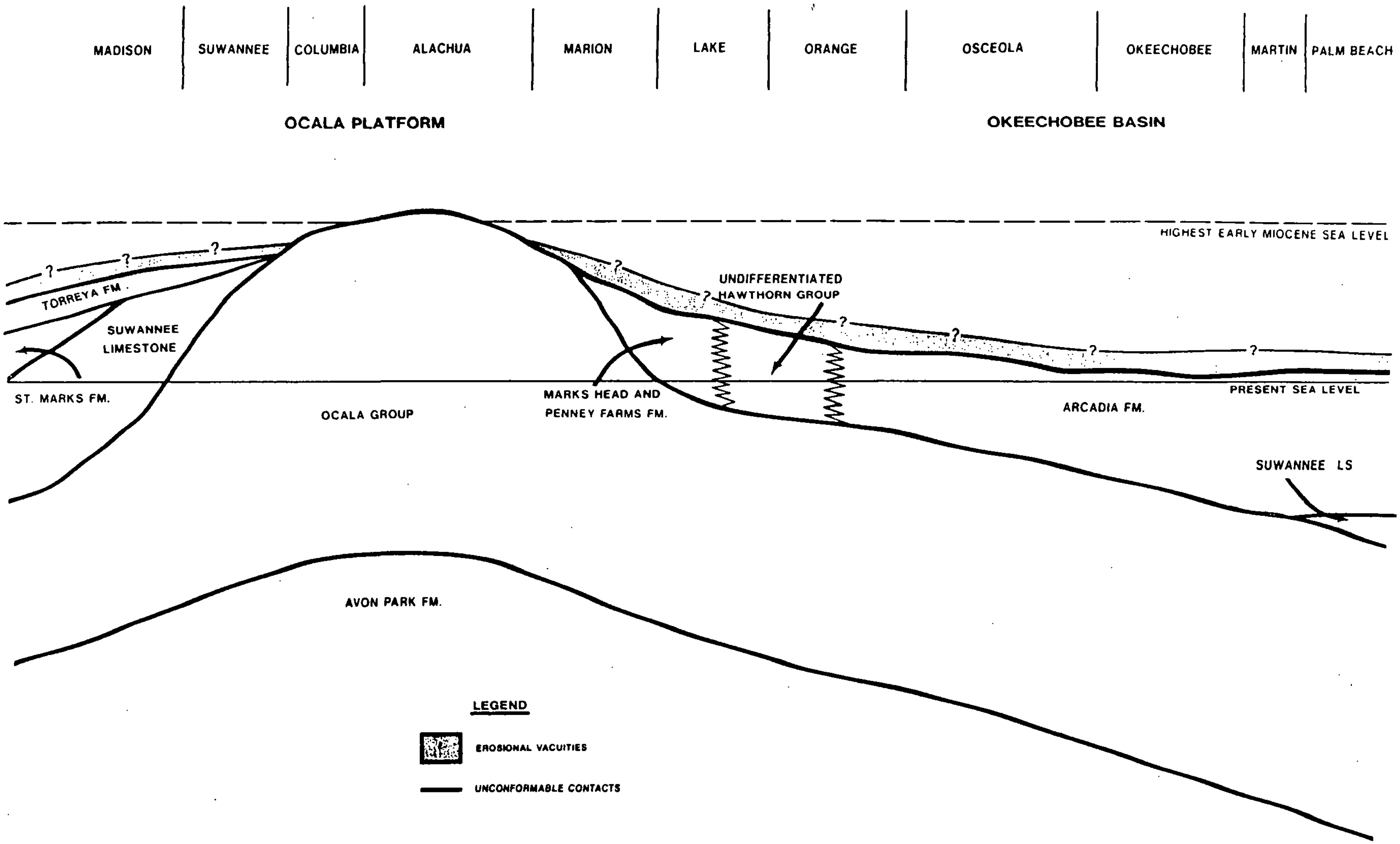


Figure 69. Cross section showing reconstructed stratigraphic sequence at the end of the Early Miocene.

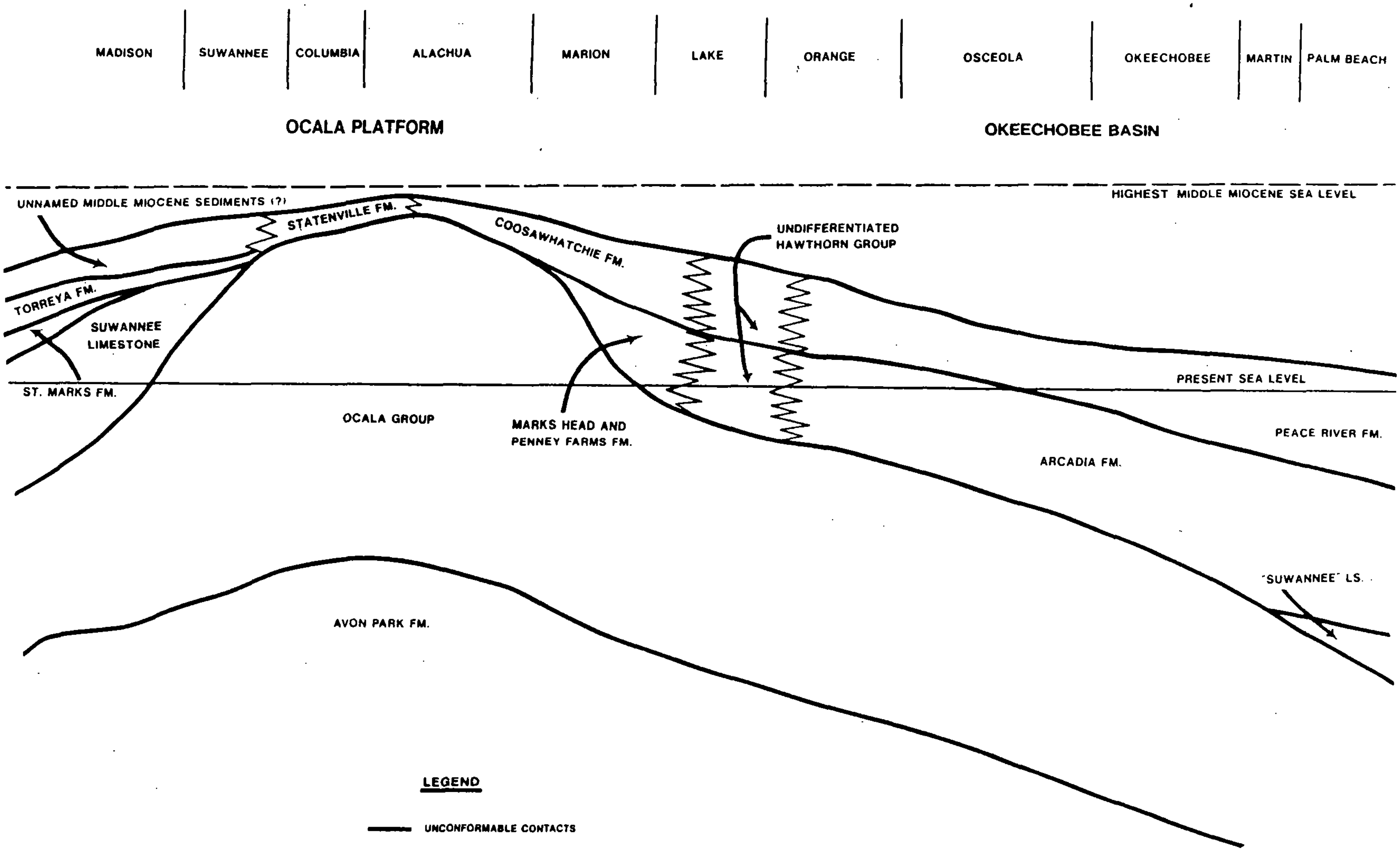


Figure 70. Cross section showing reconstructed stratigraphic sequence at the end of Middle Miocene.

the peninsula was probably entirely submerged. The Peace River and Coosawhatchie Formations were deposited in the peninsular area while an unnamed unit was deposited in the eastern panhandle. Mammal faunas from this time are not well represented. MacFadden and Webb (1982) note sites in Jefferson and Alachua Counties that may be Barstovian age NALMA (Langhian and Serravalian) with possible Barstovian faunas from the Central Florida Phosphate District. In the Central Florida Phosphate District this fauna was collected from sediments immediately above the Arcadia Formation. These sediments were subsequently covered by estuarine and marine sediments of the Peace River Formation (Webb and Crissinger, 1983).

Following the mid-Middle Miocene high stand, sea level began to decline and more of the Florida Platform was exposed. The land area continued increasing into the Late Miocene as the seas continued to recede (Figure 71). There is no record of deposition during this time in the eastern panhandle or the northern peninsular area. In the southern peninsula the upper most portions of the Peace River Formation (incuding the Bone Valley Member) were deposited. The highest sea levels of the Late Miocene and Early Pliocene did not inundate much of the peninsula. During the Late Miocene and Early Pliocene, terrestrial vertebrates were abundant, as indicated by the fauna at the Love Bone Bed in western Alachua Cunty (the only Clarendonian [Tortonian] site) and the faunas at many other Hemphillian (latest Miocene and Early Pliocene) sites.

During the Pliocene and Pleistocene sea levels fluctuated but, judging from data presently available, did not completely cover the state. Deposition appears to have been limited to the southern one-third of Florida and the coastal areas. Erosion breached the Hawthorn Group overlying the Ocala Platform and removed significant amounts of sediment from the peninsula (Figure 72). This erosional episode continues today.

There are problems associated with comparing the Vail and Mitchum (1979) sea level curve to the distribution of Hawthorn Group sediments in Florida. These problems arise when attempting to correlate the occurrence of some Hawthorn sediments presently well above sea level with a paleo-sea level represented as being at or very near present sea level. Further research is required concerning the actual elevations of paleo-sea levels in order to understand the relationships of these levels to the lithostratigraphic units onshore.

PALEOENVIRONMENTS

The Miocene sediments of Florida were apparently deposited in a number of complex depositional environments. Environments range from prodeltaic to open, shallow marine, carbonate bank. Previous workers (Puri 1953; Puri and Vernon, 1964) referred to continental (terrestrial), deltaic, and marine conditions. However, the sediments assigned to the Hawthorn Group by this investigation were deposited only under marine or peri-marine conditions that seemed to have ranged from prodeltaic and shallow to subtidal marine, to intertidal and supratidal. Terrestrial sediments occur only as paleosoils and weathered residuum of the Hawthorn sediments.

In northern peninsular Florida the Penney Farms and Marks Head Formations appear to have been deposited under shallow marine conditions. This is based on the occurrence of a shallow water fauna of *Balanus, Ostrea* and other mollusks (*Pecten, Cardium, Chione,* etc). Intraclasts are commonly recognized in the Penney Farms and Marks Head, which suggests deposition in a shallow water environment with periodic episodes of storm- or tidally-induced high energies. That the shoreline was located west of the present outcrop is indicated by the occurrence of the vertebrate remains in the Penney Farms described by MacFadden (1980). The presence of palygorskite-rich beds within the two formations suggests a nearshore, coastal-lagoonal environments (Weaver and Beck, 1977).

The Coosawhatchie Formation is also thought to have been deposited in a subtidal, shallow marine environment. The Coosawhatchie contains significantly fewer carbonate beds and is much more sandy than the underlying units. Sea level seems to have risen to its Miocene maximum height in the Middle Miocene, during Coosawhatchie deposition. As the sea transgressed, the palygorskite-producing zones of the peri-marine environment were reworked, incorporating palygorskite throughout the unit.

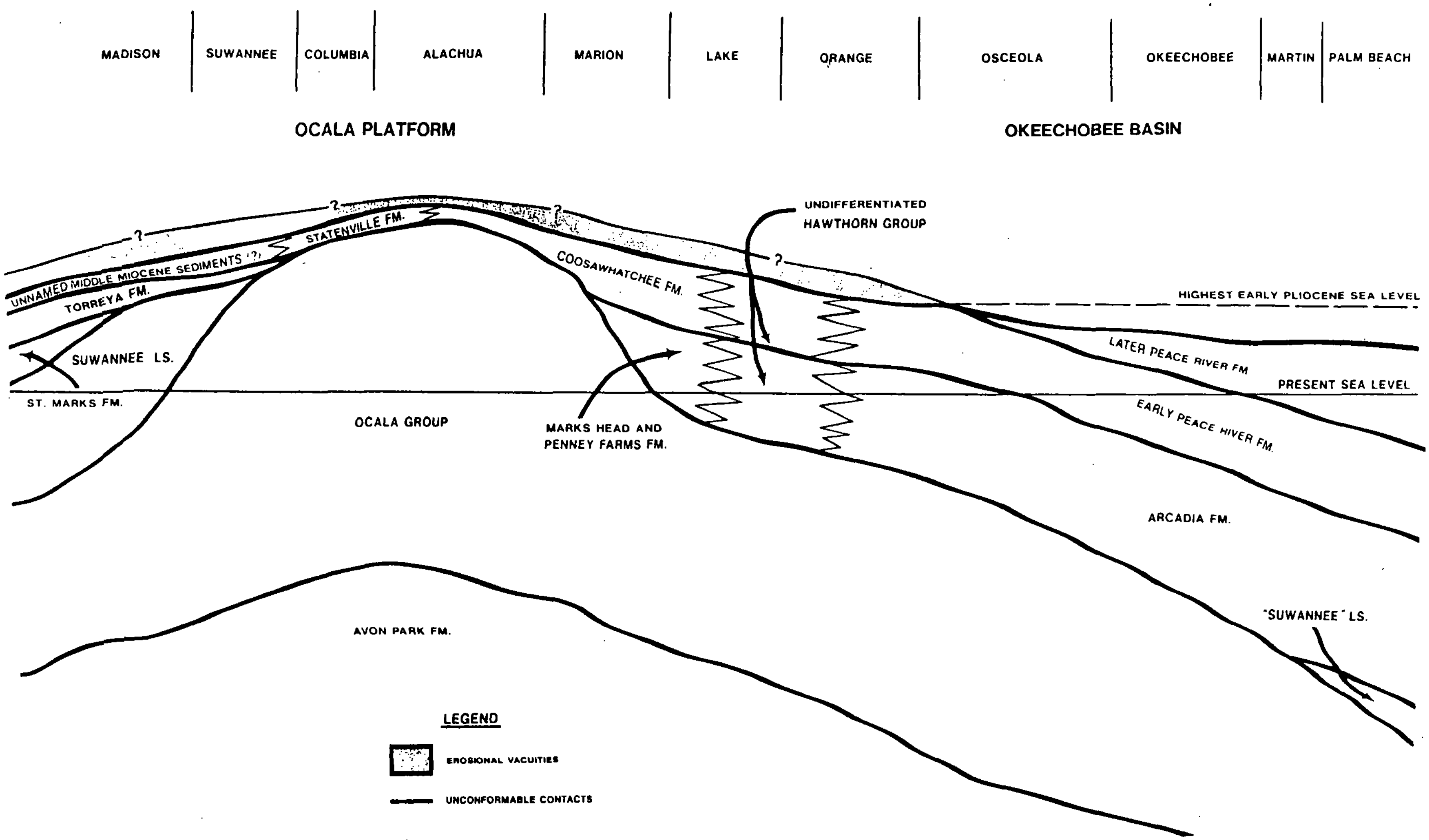


Figure 71. Cross section showing reconstructed stratigraphic sequence at the end of the Early Pliocene.

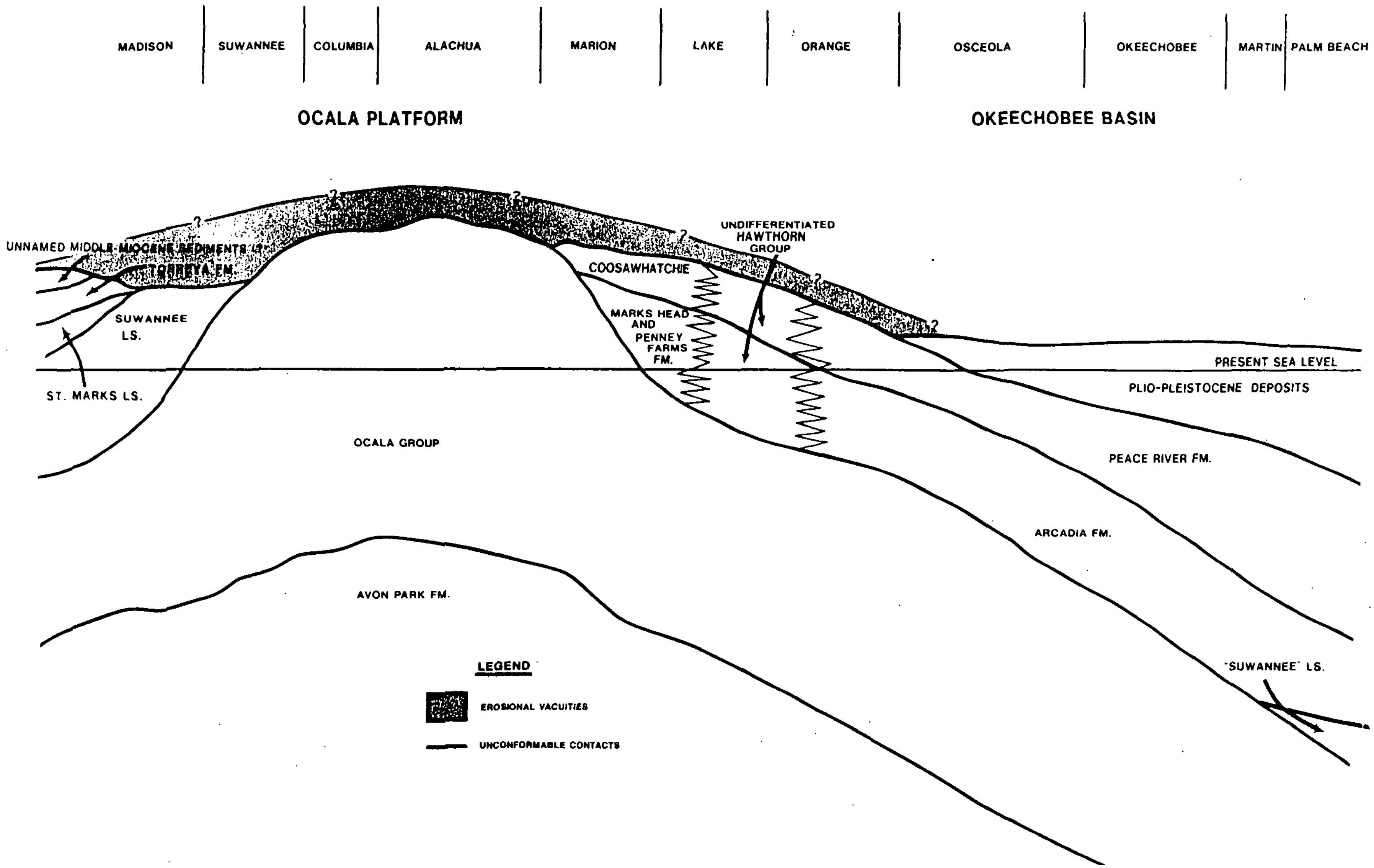


Figure 72. Cross section showing stratigraphic sequence occurring at present.

Sediments assigned to the Statenville Formation crop out along parts of the Suwannee and Alapaha Rivers. These sediments are often strongly crossbedded and contain thin dolomite laminae. Puri and Vernon (1964) thought that the laminae represented algal layers. Associated with the thin dolomite layers are mudcracks, palygorskite beds and opaline cherts. These features suggest a supratidal environment for some of the sediments, while the crossbedded zones suggested nearshore, shallow subtidal to, possibly, intertidal conditions. The occurrence of the opaline cherts is interesting since their occurrence and association with palygorskite and dolosilt (McFadden, 1982) is suggestive of the development of evaporative conditions and highly alkaline waters (Upchurch et al., 1982).

In southern Florida a shallow marine carbonate platform existed throughout a large portion of the Miocene. Siliciclastics were transported onto this carbonate bank from the north and east by southward flowing longshore currents. The Arcadia Formation developed in this environment. King (1979) suggested a quiet water lagoon, much like the present Florida Bay, for the deposition of the Tampa Member of the Arcadia. Similar depositional environments probably continued throughout the deposition of the Arcadia, although the water depths may have increased towards the southeast in response to subsidence of the platform in southern Florida. The Nocatee Member represents a higher energy, more open, near-shore marine environment that occurred on the southeast edge of the carbonate bank during Tampa deposition. The Nocatee grades westward into a very sandy facies of the undifferentiated Arcadia and northwestward into the Tampa Member.

The Peace River Formation represents the flood of siliciclastics that entered southern Florida during the Middle Miocene. The carbonate bank environment was overrun by the siliciclastics, which restricted the deposition of carbonate beds to limited areas. This change was, in part, a response to the rise in sea level in the Middle Miocene and the continued influx of large amounts of siliciclastics from the north. In the northern portion of the area of its occurrence, the Peace River was deposited in a shallow marine to brackish water environment as indicated by the occurrence of shallow water forms of *Balanus* and *Ostrea* in the carbonate beds. Further south (particularly southeasterly) open marine conditions prevailed as suggested by the abundance of planktonic foraminifera in Peace River sediments in Martin County.

The Bone Valley Member of the Peace River Formation is a most interesting unit not only from the standpoint of its phosphate resources but also from the depositional environments it represents and the questions it raises. Early investigators (Eldridge, 1893; Matson and Clapp 1909; Matson and Sanford, 1913; and others) believed that the Bone Valley resulted from the reworking of pre-existing Hawthorn residuum by rivers and the advancing Pliocene sea. Cooke (1945) believed that it was in part residual from the Hawthorn and in part estuarine. Webb and Crissinger (1983) indicate a marine depositional environment for much of the Bone Valley Member. Portions of the Bone Valley were deposited in a more nearshore, higher energy environment while others were laid down in a quieter, shallow marine environment such as an embayment or lagoon. The proximity to land is demonstrated by the occurrence of terrestrial vertebrates mixed with marine vertebrates. This author believes that the Bone Valley Member contains reworked (pre-existing) phosphate derived updip from the older parts of the Hawthorn, gravel sized clasts of phosphatized dolomite, and phosphate formed in the marine environment during Bone Valley deposition. The late phase (very Late Miocene or very Early Pliocene) gravel bed that was classically called the Bone Valley Formation or Gravel is reworked from pre-existing phosphorites. This bed was deposited in freshwater rivers to brackish water, tidally influenced environments.

The depositional environment of sediments assigned to the Torreya Formation of the Hawthorn Group in the eastern panhandle has been discussed by Weaver and Beck (1977). They suggest that these sediments and correlative sediments in southwest Georgia were deposited in a tidally influenced perimarine environment. The environments present ranged from variably brackish to more normal marine waters. This interpretation is based on the occurrence of palygorskite and dolomite, which they believe required more brackish water conditions to form and the occurrence of marine to brackish water diatoms. There were periodic episodes of high energy (perhaps storms) which could have developed intraclast beds within the unit. Limestones present in the lower Torreya suggest a shallow, subtidal marine environment during deposition.

The Hawthorn Group of the Gulf Trough contains a greater abundance of carbonate beds than is present eastward in the panhandle. It appears that this accumulation of carbonate with incorporated

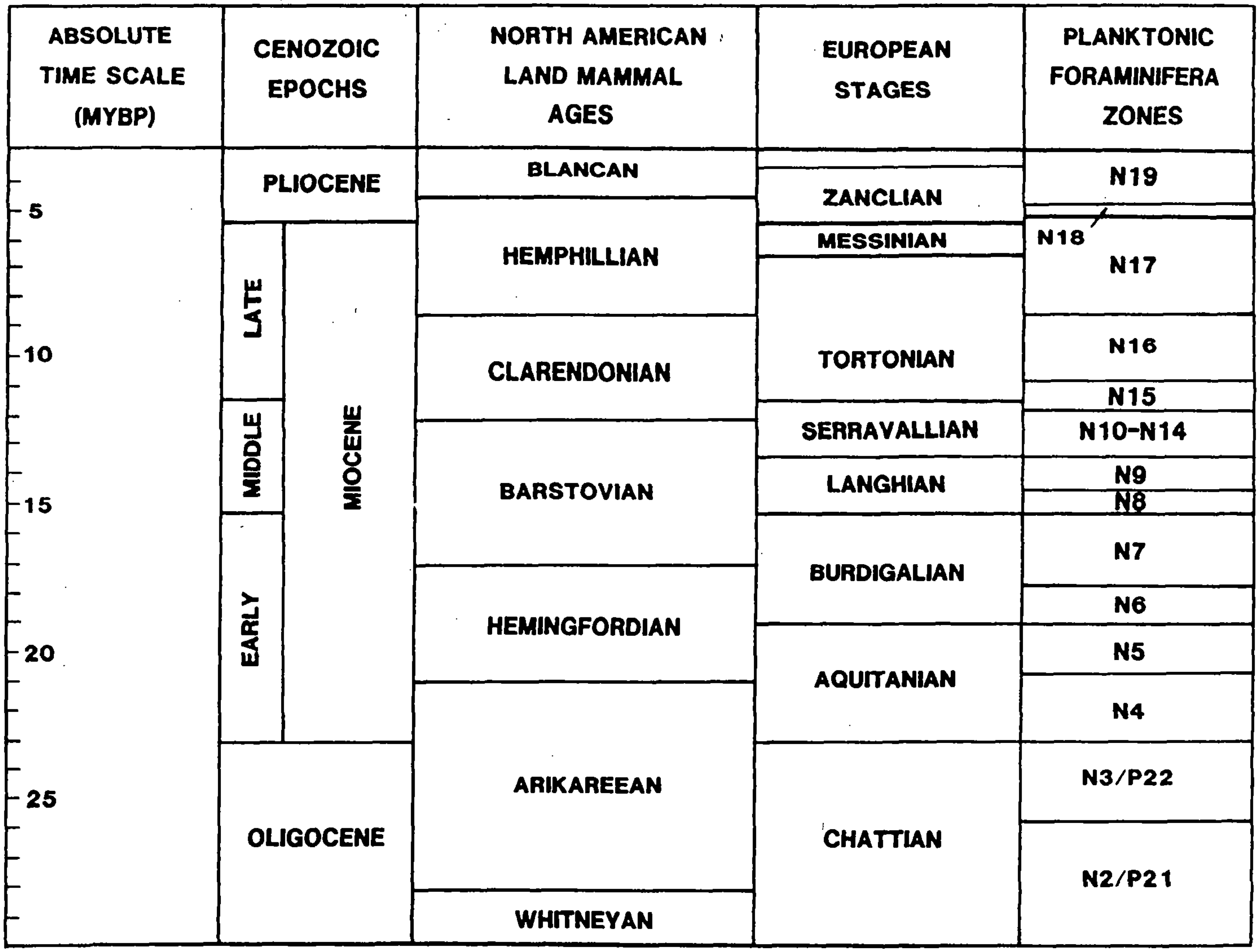


Figure 73. Relation of Mammal ages to planktonic foraminifera time scale (after Webb and Crissinger, 1983).

siliciclastics was deposited in a lagoon or embayment environment prior to the time when siliciclastics flooded the area. When large amounts of siliciclastics entered the area, carbonate deposition was severely limited.

HAWTHORN GROUP GAMMA-RAY LOG INTERPRETATION

Gamma-ray logs are of particular importance to the investigator studying the complex section of the Hawthorn Group. The gamma-ray activity in the Hawthorn Group sediments is generally significantly higher than subjacent or suprajacent formations, thus allowing the delineation of this unit. Also, since these sediments are often partially or entirely cased off during well construction, the ability of gamma-ray probe to obtain information through casing is most important. In the course of this study gamma-ray logs were the only geophysical logs used. For a discussion of resistivity logs of the Hawthorn Group sediments see Johnson (1984).

The Hawthorn Group shows significant stratigraphic and lithologic variation from one area of the state to another. As a result the gamma-ray log discussion is subdivided into sections as shown in Figure 1.

NORTH FLORIDA

The Hawthorn Group of northern Florida consists of a complex sequence of siliciclastics and carbonates containing varying percentages of uranium-bearing phosphate minerals. The resultant gamma-ray log shows widely varying peak intensities (Figure 74). The patterns of peaks are similar throughout much of the area from Duval County west to western Hamilton County and from Nassau County south to southern Putnam County. The Hawthorn thins and the gamma-ray signature changes somewhat south of Putnam County in Marion, Lake and northwestern Orange Counties. This is due both to erosional removal of the upper sediments and to less deposition in the area between the Ocala Uplift and the Sanford High.

A typical gamma-ray log from the north Florida area (Figure 74) consists of five generalized zones. However, the pattern may show significant variation in the intensities of peaks and thicknesses of peak groups. Formational correlation with the gamma-ray signature is relatively consistent. The upper, high intensity zone and part of the subjacent lower intensity zone correlate with the Coosawhatchie Formation and, where it is present, the Statenville Formation. The Marks Head Formation correlates with part of the low intensity zone, the underlying higher intensity zone, and the upper portion of the second low intensity zone. The Penney Farms Formation incorporates the remainder of this low intensity zone and the basal, high to very high intensity zone. The underlying Ocala Group and occasionally the Suwannee Limestone have significantly lower generalized signatures than the sediments of the Hawthorn Group. The formational correlations with the gamma-ray signature are shown in Figure 74. The upper and lower boundaries of the Hawthorn Group are generally easily picked on the gamma-ray logs. However, caution must be exercised in making formational identifications based solely on the signatures.

SOUTH FLORIDA

Intensities of gamma-ray activity in the Hawthorn Group sediments show similar ranges to those recognized in the northern portion of the peninsula. However, the generalized gamma-ray signature is quite different. Figure 75 shows a typical southern Florida gamma-ray log (compare with the northern Florida log, Figure 74). As is the case in northern Florida, the Hawthorn sediments in this area have, in general, significantly higher gamma-ray signatures than the subjacent or suprajacent units.

The Hawthorn Group in southern Florida is somewhat less complex than its northern counterpart. In this area the Hawthorn is generally composed of a siliciclastic upper unit (the Peace River Formation) and a lower carbonate unit (the Arcadia Formation). The Hawthorn becomes more complex to the east due to a greater siliciclastic influx and subsequently the gamma-ray signature changes. These variations are discussed by Gilboy (1983). Several logs showing the more typical range of variations are shown in Figures 76, 77, and 78.

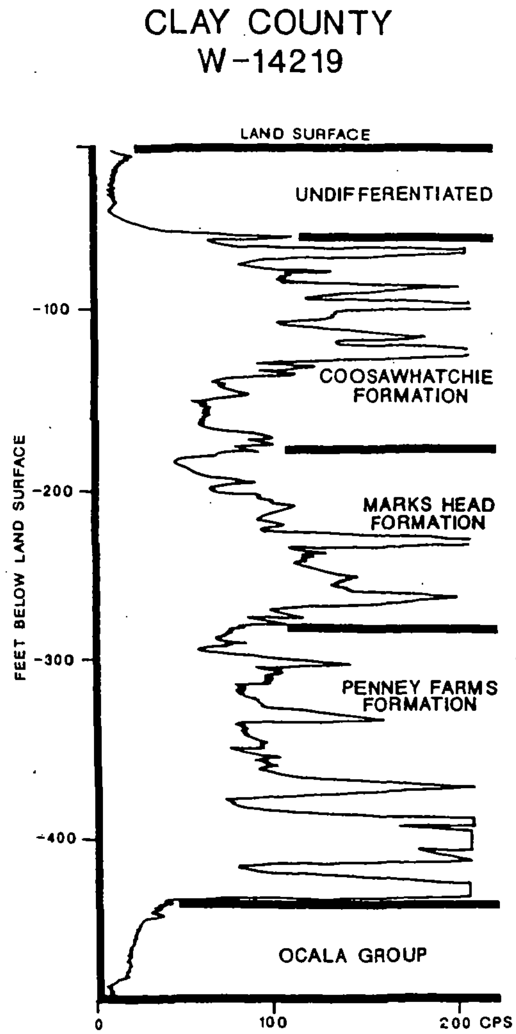


Figure 74. Gamma-ray log, Jennings #1, W-14219, Clay County.

The least complex area is the western half of southern Florida from Polk County southward to Lee and Collier Counties. A typical log for this area, as shown in Figure 79, consists of a number of distinct intensity zones. The uppermost zone is a relatively low intensity zone corresponding to the Peace River Formation. This is underlain by a zone of numerous higher intensity peaks which represent the upper, undifferentiated Arcadia Formation. Below this zone, the intensity drops to the lowest point in the Hawthorn Group. The intensity increases below the low intensity zone to a moderate intensity in basal sediments of the Arcadia Formation. At the base of the Arcadia Formation, the base of the Hawthorn Group, the gamma-ray intensity drops significantly at the contact with the "Suwannee" Limestone.

Variations of the gamma-ray intensity are often greatest in the Peace River Formation. The intensity increases as the phosphate content increases in the phosphate district. The gamma-ray signature of the upper section is most intense when the Bone Valley Member of the Peace River Formation is present (Figure 76). In part of the eastern portion of southern Florida and the extreme southern end of the peninsula, the gamma-ray activity of the Peace River Formation is generally low with only a few high peaks. In parts of Osceola, Brevard and Indian River Counties the Peace River Formation may contain significant phosphate. The resultant gamma-ray signature is high.

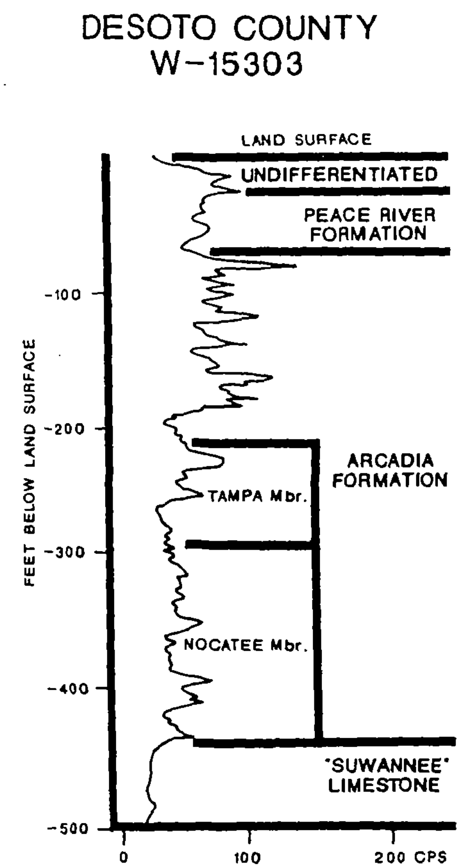


Figure 75. Gamma-ray log, R.O.M.P. 17, W-15303, DeSoto County.

In the eastern portion of southern Florida, south from and including Brevard County and east from the Polk-Osceola County line, the gamma-ray signature is more complex (Figure 77). In the northern part of this area, the Hawthorn is thin and the signature has many high intensity peaks. South from this area the Hawthorn thickens and the generalized signature contains a wider range of intensities (Figure 78). Throughout the eastern half of southern Florida, the Peace River Formation is characteristically of lower gamma-ray intensity than the underlying Arcadia Formation, although a wide variation exists (Figures 77 and 78). The top of the Peace River Formation is usually marked by a peak that is significantly higher than the background. This represents a concentration of phosphate at the post-Hawthorn unconformity. The contact between the Arcadia and Peace River Formations is generally marked by an increase in the abundance of large peaks in the Arcadia. Characteristically, the basal Hawthorn Group sediments contain the greatest number of high intensity peaks and the most intense peaks (Figures 77 and 78).

Underlying the Hawthorn Group throughout the eastern section are sediments with low gamma-ray activities. In portions of the eastern section, the Hawthorn is unconformably underlain by limestones of the Ocala Group which have very low activities. In other areas the Hawthorn is underlain by "Suwannee" Limestone or, in some cases, unnamed Lower Miocene limestones both with gamma-ray signatures much lower than the overlying section.

POLK COUNTY
R.O.M.P. 45-2

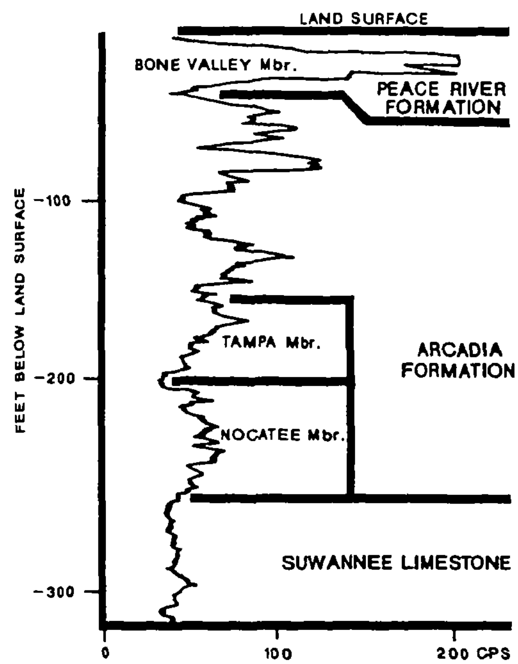


Figure 76. Gamma-ray log, R.O.M.P. 45-2, Polk County.

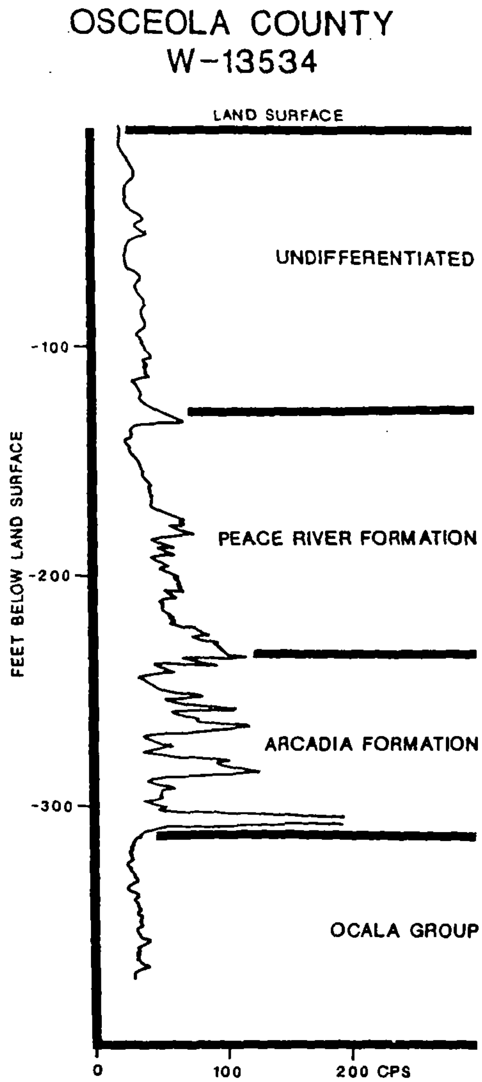


Figure 77. Gamma-ray log, Osceola #7, W-13534, Osceola County.

INDIAN RIVER COUNTY
W-13958

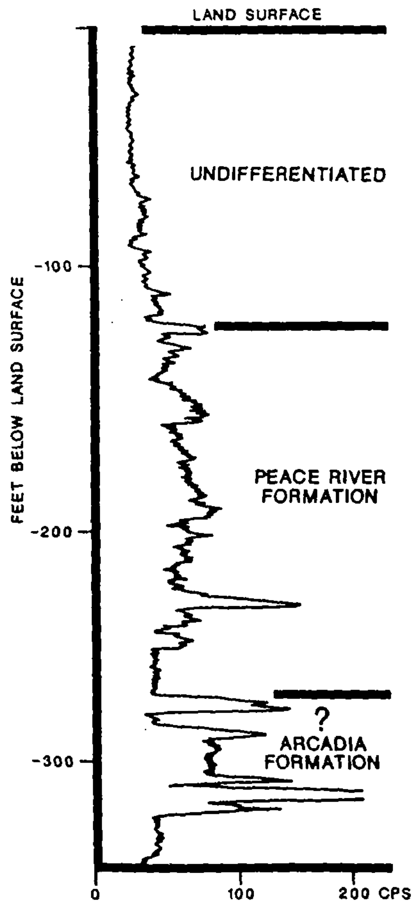


Figure 78. Gamma-ray log, Phred #1, W-13958, Indian River County.

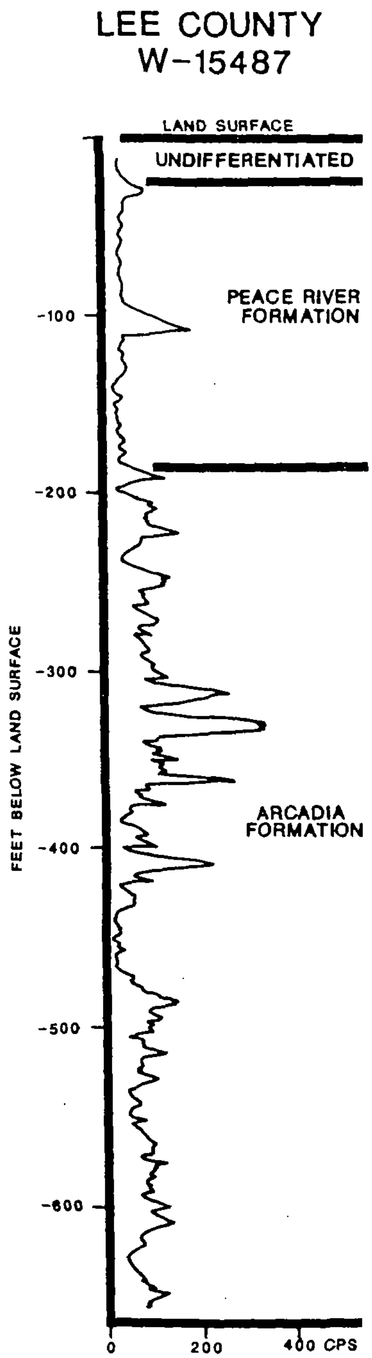


Figure 79. Gamma-ray log, Cape Coral #1, W-15487, Lee County.

EASTERN PANHANDLE

The Hawthorn Group sediments of the eastern Florida panhandle are lithologically different from the Hawthorn in the northern peninsula. This difference is also recognizable when comparing gamma-ray logs from these areas (compare Figure 80 with Figure 74). The northern axis of the Ocala Platform serves as the line separating the two areas, with the Hawthorn Group thickening away from the axis to the east and west. The Hawthorn sediments of the eastern panhandle are predominantly clays, sandy clays and clayey sands with occasional carbonate lenses and contain minor percentages of phosphate. The percentage of carbonate beds increases in western Leon County and westward into the Gulf Trough and Apalachicola Embayment. Figures 80 and 81 show the gamma-ray signature variation in the eastern panhandle.

The typical gamma-ray signature of the Hawthorn Group in the area east of the Gulf Trough is shown in Figure 81. The Hawthorn Group (Torreya Formation) has a gamma-ray signature that is well above the intensity of the subjacent and suprajacent units. In the Gulf Trough the Hawthorn Group thickens. The gamma-ray signature there appears more like that of the peninsular Hawthorn with many higher-intensity peaks separated by low intensity zones.

SUMMARY

1) The Hawthorn Formation has long been considered a complex and unusual unit. The complexity of the strata is the result of interbedding and mixing of carbonate and siliciclastic components in association with the occurrence of phosphate and palygorskite. The complex nature of the Hawthorn can best be understood if the unit is raised to group status and formations are identified within it. This author formally proposes upgrading of the Hawthorn Formation to group status in Florida. New formations are also formally proposed to subdivide the Hawthorn Group.

2) The Hawthorn Group occurs throughout much of Florida and the Coastal Plain of Georgia. In Florida, the Hawthorn is primarily a subsurface unit, although it crops out along the flanks of the Ocala Platform, along the southwest coast of the state, and in limited areas of the eastern panhandle. It is absent from the crest of the Ocala Platform and the Sanford High due to erosional removal.

3) Evidence suggests that sediments of the Hawthorn Group covered the Ocala Platform during Miocene time. The occurrence of outliers of these sediments, the hard rock phosphate and silicified Eocene and Oligocene carbonates, suggests the presence of the Hawthorn over the crest of the platform.

4) The formations of the Hawthorn Group vary from north Florida into south Florida and from north Florida into the eastern panhandle. The Ocala Platform and the Sanford High affected deposition of these sediments, allowing the regional grouping of the formations.

5) The Hawthorn Group in north Florida occurs east of the crest of the Ocala Platform and north of the Sanford High in central Florida. The sediments of the Hawthorn thin in the area between the Ocala Platform and the Sanford High. It appears that the section is thinned due to both erosion and decreased deposition. South of this area the north Florida Hawthorn sediments grade into the south Florida Hawthorn through an area of undifferentiated Hawthorn Group.

6) The area of transition between the Hawthorn Group of north Florida and that of south Florida occurs in an area from central Lake County to northwestern Orange County. This area is between the Ocala Platform and the southern edge of the Sanford High. Within this zone the component formations of the Hawthorn Group are difficult to recognize and as a result, the section remains undifferentiated Hawthorn Group.

7) The north Florida Hawthorn Group consists of (in ascending order) the Penney Farms Formation, the Marks Head Formation, the Coosawhatchie Formation and the Statenville Formation. All of these formational names are new to Florida stratigraphy. The Marks Head, Coosawhatchie and Statenville Formations and the Charlton Member of the Coosawhatchie Formation are extended into Florida from Georgia where their use is currently being formalized (Huddlestun, in press).

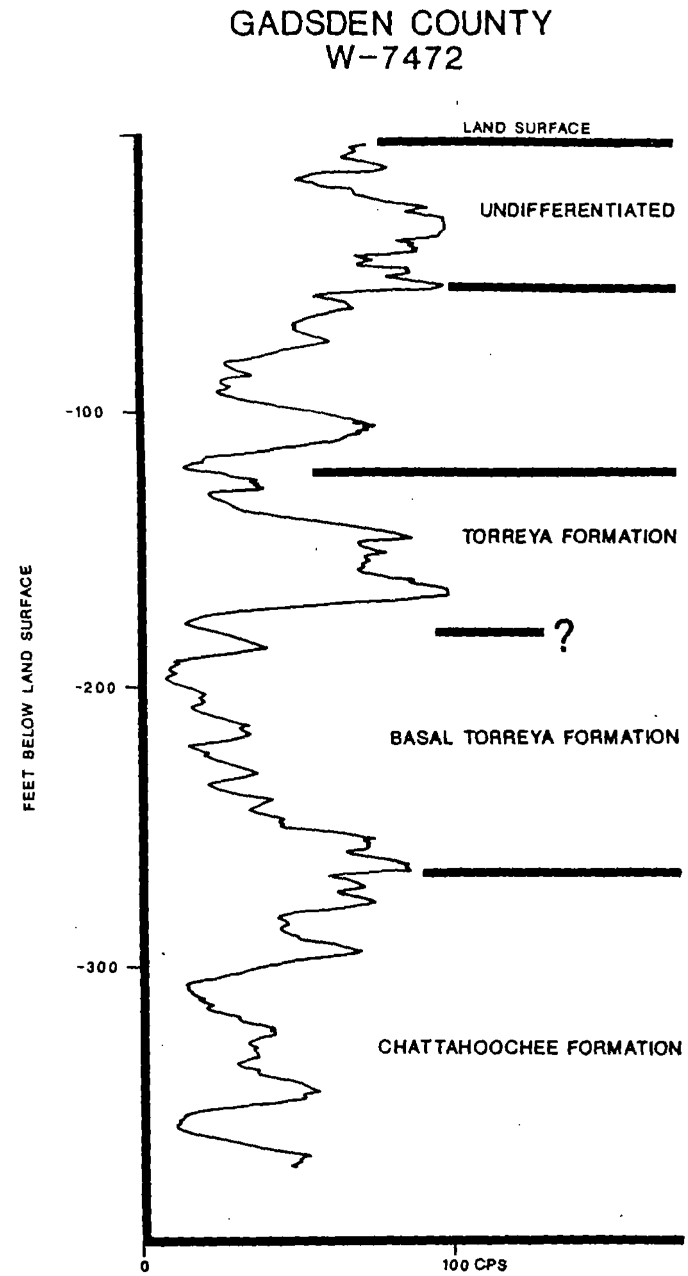


Figure 80. Gamma-ray log, Owenby #1, W-7472, Gadsden County.

MADISON COUNTY
W-15515

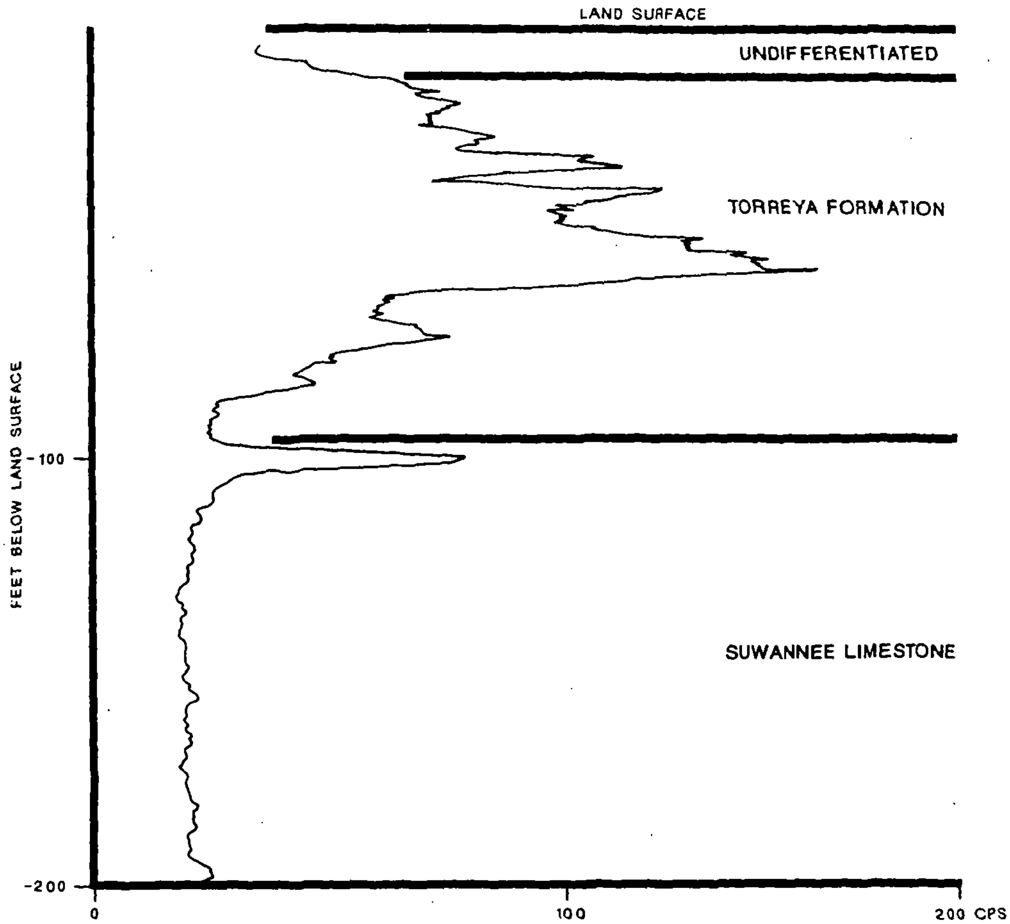


Figure 81. Gamma-ray log, Howard #1, W-15515, Madison County.

8) The Penney Farms Formation is a new name proposed for the basal Hawthorn sediments in north Florida. The type section of the Penney Farms Formation is in core W-13769, Harris #1, located near Penney Farms in central Clay County (SW¼, SE¼ Section 7, Township 6S, Range 25E). It consists of interbedded dolomites and siliciclastics with carbonate being most abundant in the lower portion and siliciclastics in the upper portion. The dolostones are variably quartz sandy, phosphatic and clayey, often containing zones of intraclasts. The siliciclastics vary from clayey sands to sandy clays with varying percentages of phosphate and dolomite. The clays present are smectite, palygorskite, illite and sepiolite.

The Penney Farms Formation unconformably overlies the Ocala Group or, in a few areas, the Suwannee Limestone. It is overlain unconformably by the Marks Head Formation. The top of the Penney Farms in cores ranges from -333 feet MSL (-101 meters) in W-14619 in Duval County to +80 feet MSL (+24 meters) in W-14641 in Alachua County. This unit is thickest in the Jacksonville Basin where more than 155 feet (47 meters) of it are present. The Penney Farms sediments are absent from the crest of the Ocala Platform and the Sanford High. The unit dips generally to the northeast from the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations in dip are common.

Few fossils are present in the Penney Farms Formation. Dateable faunas encountered indicate an early to middle Aquitanian age (Early Miocene) for this unit. These equate with Zone N.4 and possibly early

N.5 of Blow (1969). The Penney Farms Formation correlates with the Parachucla Formation in Georgia, the lower part of the Arcadia Formation in south Florida and the Chattahoochee Formation in the eastern Florida panhandle. It is slightly older than the Pungo River Formation of North Carolina.

9) The Marks Head Formation is introduced here for sediments of the Florida Hawthorn Group that correlate with the Marks Head Formation in Georgia as recognized by Huddlestun (in press). A reference section in Florida is in core W-14219, Jennings #1, Clay County, Florida (SE¼, SE¼, Section 27, Township 4S, Range 24E).

The Marks Head is the most complexly interbedded unit of the Hawthorn Group. Lithologically, it consists of interbedded clays, quartz sands, and carbonate (usually dolostone), each with varying percentages of quartz sand, clay, carbonate and phosphate. The clays present in the Marks Head are palygorskite, smectite, illite and sepiolite.

The Marks Head unconformably overlies the Penney Farms Formation throughout much of its extent. It is, in turn, overlain unconformably by the Coosawhatchie Formation. The top of the Marks Head ranges from -260 feet MSL (-79 meters) in W-14619, Duval County to +114 feet (35 meters) in W-14641 Alachua County. This unit is absent from the crest of the Ocala Platform and the Sanford High. It reaches a maximum thickness of 130 feet (40 meters) in W-12360, Bradford County.

The Marks Head dips generally to the northeast from the flanks of the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations are common.

The age of the Marks Head Formation in Florida is inferred from the dateable faunas found in Georgia, since no faunas have been identified in the Florida portion. The Marks Head is Burdigalian age (late Early Zone N.6 or very early N.7 of Blow (1969).

This unit correlates with the Torreya Formation of the Florida panhandle, part of the Arcadia Formation of south Florida, and the lower Pungo River Formation of North Carolina.

10) The Coosawhatchie Formation is introduced here for the upper unit of the Hawthorn Group in northern peninsular Florida. It is a southern extension of the Coosawhatchie Formation of Georgia as introduced by Huddlestun (in press). A reference section in Florida is in core W-13769, Clay County (SW¼, SE¼, Section 7, Township 6S, Range 25E). Lithologically the Coosawhatchie consists of carbonates, quartz sands and clays. The upper part of the formation is characteristically a very sandy, clayey dolostone with interbedded siliciclastics and variable percentages of phosphate. The lower part is characteristically clayey, dolomitic sand with interbedded clay and carbonate and variable amounts of phosphate. Clay minerals present include smectite, palygorskite, sepiolite and illite.

The Coosawhatchie Formation unconformably overlies the Marks Head Formation and unconformably underlies undifferentiated post-Hawthorn sediments. Its upper beds appear to grade laterally into the Statenville Formation. The top of the Coosawhatchie ranges from -93 feet MSL (-28 meters) in W-14477, Putnam County to +168 feet MSL (51 meters) in W-14641, Alachua County. This unit is also absent from the Ocala Platform and the Sanford High. The thickest known occurrence of the Coosawhatchie is in W-14619, Duval County, where it attains a thickness of 222 feet (68 meters). This unit generally dips northeasterly from the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations in dip are common.

The age of the Coosawhatchie Formation is thought to be Middle Miocene (early Serravalian) based on diatoms and planktonic foraminifera. It is correlated with the Peace River Formation of south Florida, the lower part of the shoal River Formation in the panhandle, and much of the Pungo River Formation in North Carolina.

11) The Charlton Member of the Coosawhatchie Formation represents a reduction of the Charlton Formation to member status, as used by Huddlestun (in press). A reference section for the Charlton Member in Florida is in W-13815, Nassau County (NW¼, NW¼, Section 32, Township 3N, Range 24E). It consists of interbedded carbonates and clays that are variably quartz sandy and slightly to nonphosphatic.

The Charlton overlies conformably and interfingers with the undifferentiated Coosawhatchie Formation. It unconformably underlies the undifferentiated post-Hawthorn sediments. The top of the Charlton ranges from -38 feet MSL (-12 meters) in W-14619, Duval County to +109 feet (33 meters) in W-14283,

Bradford County. Its maximum thickness is approximately 40 feet (13 meters) in W-13815, Nassau County. The occurrence of the Charlton Member is spotty throughout the northeasternmost part of the state.

The age of the Charlton Member is considered to be Middle Miocene by Huddlestun (in press), based on the mollusk fauna and the lithostratigraphic relationships.

12) The Statenville Formation is a formational name extended into Florida from Georgia where it was described by Huddlestun (in press). A reference section for Florida is in core W-15121, Hamilton County (NE¼, NW¼, Section 3, Township 2N, Range 12E). The Statenville is characteristically quartz sand with common to abundant phosphate, interbedded with clays and dolostones. One of the diagnostic features of this unit is its thin bedded and cross bedded nature.

The Statenville conformably overlies part of the Coosawhatchie Formation and unconformably underlies undifferentiated post-Hawthorn sediments. In Florida, this formation is recognized only in the limited area of Hamilton and Columbia Counties. The maximum thickness is 87 feet (26.5 meters) in W-15121, Hamilton County.

The age of the Statenville is believed to be Middle Miocene (Serravalian) by Huddlestun (in press). Vertebrate fossils collected from it suggest a late Middle Miocene age. A reworked zone at the top of the Statenville contains Late Miocene vertebrate fossils.

13) The south Florida Hawthorn Group consists of (in ascending order) the Arcadia Formation with the Nocatee and Tampa Members and the Peace River Formation with the Bone Valley Member. The Arcadia and Peace River Formations and the Nocatee Member are new names introduced here. The Tampa and Bone Valley Members are former formational units reduced to member status within the newly proposed Hawthorn Group framework.

14) The Arcadia Formation is a new name proposed here for the lower Hawthorn carbonate section of south Florida. The type section is in the core W-12050, DeSoto County (SE¼, NW¼, Section 16, Township 38S, Range 26E). The Arcadia Formation, with the exception of the Nocatee Member, is predominantly carbonate with varying percentages of quartz sand, clay and phosphate. Thin quartz sand beds and clay beds are present but not abundant.

The Arcadia Formation unconformably overlies the Ocala Group in part of south Florida and the "Suwannee" Limestone in the remainder. In some areas the contact between the Arcadia and the "Suwannee" appears conformable. The Arcadia is usually overlain by the Peace River Formation but, where the Peace River is absent, the Arcadia is overlain by undifferentiated post-Hawthorn sediments. The top of the Arcadia ranges from -440 feet MSL (-134 meters) in W-15493, Monroe County, to +112 feet MSL (34 meters) in W-13269, Polk County. It ranges in thickness up to more than 600 feet (183 meters). In general, the Arcadia dips to the southeast at approximately 5 feet per mile (0.9 meters per kilometer).

The Arcadia Formation has yielded few dateable fossils. Mollusk specimens in the upper portion indicate a correlation with the Torreya Formation of the eastern panhandle and the Marks Head Formation of north Florida and Georgia. This places the Arcadia Formation as no younger than mid-Burdigalian (late Early Miocene). The lower part of the Arcadia appears to equate with the Penney Farms Formation of north Florida, the Chattahoochee Formation in the eastern panhandle and the Parachucla Formation in eastern Georgia.

15) The Tampa Member of the Arcadia Formation represents a reduction in status for the Tampa from formation to member. The reduction is justified based on the limited areal extent of the unit and by its variable nature which is gradational with the undifferented Arcadia Formation. The classical type area occurs around Tampa Bay in Hillsborough County. The type core is W-11541 (SE¼, NW¼, Section 11, Township 30S, Range 18E, Hillsborough County). Reference cores showing regional variation include W-11570 (Section 1, Township 33S, Range 22E, Manatee County) and W-15166 (NW¼, Section 22, Township 35S, Range 17E, Manatee County).

The Tampa Member is predominantly limestone with varying percentages of quartz sand, clay, and minor phosphate. Dolomite is generally a minor component. Phosphate is generally present in amounts less than 3 percent. Individual beds of quartz sand and clay do occur but are infrequent.

The Tampa Member overlies the "Suwannee" Limestone in areas where the Nocatee Member is not

present beneath the Tampa. The contact with the "Suwannee" often appears gradational but in the updip areas, the contact is abrupt and unconformable. When the Nocatee Member is present, it underlies the Tampa conformably. The Tampa is overlain throughout much of its extent by the undifferentiated Arcadia Formation. Where the undifferentiated Arcadia Formation is absent due to erosion, the Tampa Member is overlain by either the Peace River Formation or undifferentiated post-Hawthorn sediments. The top of the Tampa ranges from +75 feet (23 meters) MSL in Hillsborough County to -323 feet (-98.5 meter) MSL in Sarasota County. The thickness of the Tampa Member ranges up to 270 feet (82 meters).

The Tampa Member is characteristically variably fossiliferous. Most common are mollusks; with corals and foraminifera also present. Despite the presence of these fossils, no age-diagnostic species have been recognized. It is suggested that the Tampa correlates with the lower part of the Parachucla Formation in Georgia. The Tampa may correlate with the basal Penney Farms Formation in north Florida.

16) The Nocatee Member of the Arcadia Formation is a new name proposed here for the "Tampa sand and clay" unit of Wilson (1977) which occurs entirely in the subsurface. The type core is W-12050 (SE¼, NW¼, Section 16, Township 38S, Range 26E, DeSoto County).

The Nocatee Member is a complexly interbedded sequence of quartz sands, clays, and carbonates, all containing variable percentages of phosphate. It is predominantly a siliciclastic unit but becomes more carbonate-rich near the limits of the member, where it grades into the undifferentiated Arcadia Formation.

The Nocatee Member overlies "Suwannee" Limestone throughout the Nocatee's extent. The contact appears gradational. The Tampa Member conformably overlies the Nocatee throughout much of the Nocatee's extent. Occasionally, the Nocatee is overlain by the undifferentiated Arcadia Formation.

The top of the Nocatee Member ranges from -81 feet (-24.5 meters) MSL in Polk County to -639 feet (-195 meters) MSL in Charlotte County. The thickest section currently recognized is 226 feet (70 meters) in DeSoto County.

The age of the Nocatee is based solely on its relationship to the Tampa Member. This suggests an earliest Miocene age.

17) The Peace River Formation is a new name proposed for the "upper Hawthorn" clastic unit of southern Florida. The type section is in W-12050 (SE¼, NW¼, Section 16, Township 38S, Range 26E, DeSoto County). W-15303 (NE¼, NE¼, Section 14, Township 38S, Range 23E, DeSoto County) is a suggested reference section.

The Peace River Formation consists predominantly of siliciclastics with interbedded carbonate units. Phosphate is present in highly variable percentages that range into the economically important category. The clastics are calcareous to dolomitic, clayey, phosphatic quartz sands to sandy clays.

The Peace River Formation overlies the Arcadia Formation (including the Tampa Member) throughout its extent. The contact appears unconformable in the updip area and gradational downdip. It is overlain by the Tamiami Formation in parts of southern Florida and by undifferentiated post-Hawthorn sediments in the remainder of the area. The top of the Peace River Formation ranges from +175 feet (53 meters) MSL in Polk County to -150 feet (-46 meters) MSL in parts of Dade and Collier Counties. Thicknesses range to greater than 400 feet (122 meters) in central southern Florida.

The Peace River Formation often contains well preserved faunas, including foraminifera, diatoms and, in some areas, vertebrates. As a result, the range of ages this unit encompasses often can be documented. The oldest date assigned to the Peace River Formation, based on limited vertebrate faunas, is early Middle Miocene (early Serravalian). The youngest age applied to the unit is no younger than earliest Pliocene, based on planktonic foraminifera faunas.

The Peace River Formation correlates in part with the Coosawhatchie and Statenville Formations of north Florida and Georgia and the Pungo River Formation of North Carolina.

18) The Bone Valley Member of the Peace River Formation represents a reduction from formation to member status for the Bone Valley strata. This reduction is justified based on the limited areal distribution of the Bone Valley, its laterally and vertically gradational relationship with the undifferentiated Peace River Formation, and lithologic similarities with the Peace River Formation. The original type locality was in the phosphate mines west of Bartow in Polk County. No single section in the mines remains very long,

therefore, no neotype section has been erected. A reference core, W-8879 (NE¼, SW¼ Section 24, Township 29S, Range 24E, Polk County), is suggested here.

The Bone Valley Member is a clastic unit consisting of quartz sands, clays and variable, but usually high, percentages of phosphate. Characteristically, it consists of pebble- to gravel-sized and sand-sized phosphate in a quartz sand and clay matrix. The occurrence of the phosphate gravels is the most lithologically important factor in distinguishing the Bone Valley Member from the remainder of the Peace River Formation. Clay beds and quartz sand units are relatively common in the Bone Valley Member.

The Bone Valley Member unconformably overlies the carbonates of the Arcadia Formation throughout much of its areal extent. In the southern area of the Bone Valley, it interfingers with and overlies the undifferentiated Peace River Formation. The Bone Valley is overlain by undifferentiated post-Hawthorn sediments. This contact is unconformable although weathering often obscures it, creating a gradational appearance.

The top of the Bone Valley Member ranges from +175 feet (53 meters) MSL to less than +100 feet (30.5 meters) MSL. The maximum thickness reaches just over 50 feet (15 meters).

The age of the Bone Valley Member is derived entirely from vertebrate remains. The oldest ages suggested are late Early Miocene (mid-Barstovian; late Burdigalian). Most of the Bone Valley Member is late Middle to mid-Late Miocene (Clarendonian; late Serravallian to mid-Tortonian). The uppermost phosphate gravels of the original Bone Valley "Gravels" are very latest Miocene to Early Pliocene (Late Hemphillian; Messinian to Zanclian).

The Bone Valley Member correlates in part with the Coosawhatchie and Statenville Formations of northern Florida and Georgia. It also correlates in part with the Pungo River Formation of North Carolina.

19) The sediments of the eastern Florida panhandle Hawthorn Group occur in the area between the axis of the Ocala Platform and the Apalachicola River. These sediments show significant variation from the Hawthorn Group east of the platform in north Florida, facilitating the use of separate formational names. In the panhandle the sediments of the Hawthorn Group are placed entirely in the Torreya Formation.

20) The Torreya Formation of the Hawthorn Group was named by Banks and Hunter (1973) and revised by Huddlestun and Hunter (1982) and Huddlestun (in press). Their terminology is used in this paper. The type section for the Torreya Formation is located on the Apalachicola River at Rock Bluff (SW¼, Section 17, Township 2N, Range 7W, Liberty County). Reference sections designated here are in cores W-6611 (SE¼, NE¼, Section 23, Township 2N, Range 7W, Liberty County), W-7472 (SE¼, NW¼, Section 19, Township 2N, Range 3W, Gadsden County), and W-6998 (SE¼, NW¼, Section 8, Township 2N, Range 2E, Leon County). The Torreya contains two named members, the Dogtown and the Sopchoppy.

The Torreya Formation is characteristically a siliciclastic unit with increasing amounts of carbonate in the Gulf Trough area. Lithologically, the siliciclastic section is clayey quartz sand to quartz sandy clays with variable percentages of accessory minerals including dolomite, limestone and phosphate. Fuller's earth clays are an important part of the Torreya Formation in the Gulf Trough area. Phosphate is often absent from the Torreya sediments. The carbonate portion of this unit is typically a quartz sandy limestone (occasionally dolomitic to dolostone).

The Torreya Formation overlies the Chattahoochee and/or St. Marks Formations. The contact appears gradational in part of the Gulf Trough but disconformable in other areas. It is overlain unconformably by the Citronelle and Miccosukee Formations throughout much of its extent. In limited areas it is overlain unconformably by the Jackson Bluff Formation. In some areas the Torreya is overlain by undifferentiated surficial sands.

The age of the Torreya Formation based on predominantly vertebrate faunas, is mid-Early Miocene (early to mid-Burdigalian). This unit correlates with the Marks Head Formation of north Florida and south Georgia and the upper part of the Arcadia Formation of southern Florida. In the southern portion of the Apalachicola Embayment the Torreya grades into the Bruce Creek Limestone. The Torreya equates with the lower part of the Pungo River Formation of North Carolina.

21) The Dogtown Member of the Torreya Formation is the clay-rich interval in the upper Torreya in parts of Liberty, Gadsden, and Leon Counties, Florida, and Decatur County, Georgia. The type locality is

the La Camelia Mine of Englehard Minerals and Chemical Corp. in Gadsden County (Section 15, Township 3N, Range 3W). A reference core for the Dogtown is W-7472 (SE¼, NW¼, Section 19, Township 2N, Range 3W, Gadsden County).

The Dogtown Member consists predominantly of clays with thin sand and carbonate beds. The commercial clay beds are quite pure, but the other clays of this unit are often quartz-sandy, silty and occasionally dolomitic. The clay minerals associated with this unit are mainly palygorskite and smectite.

This member ranges in thickness from 15 feet (4.7 meters) to 40.5 feet (12 meters) where it is recognized in cores. Its areal extent is not presently defined. The relationship of the Dogtown to overlying and underlying units has not been accurately defined. The age is considered to be mid-Early Miocene (early to mid-Burdigalian).

22) The Sopchoppy Member of the Torreya Formation is a sandy, fossiliferous limestone of limited areal extent. Its type locality is on Mill Creek in Wakulla County (center, Section 34, Townhip 4S, Range 3W).

The Sopchoppy varies from a sandy, phosphatic, fossiliferous limestone to a dolomitic, phosphatic, quartz sand. It has only been recognized near the type locality at the present time and its thickness and extent are not defined. This member is thought to be Early Miocene based on faunal similarities with the main portion of the Torreya Formation.

23) The Hawthorn Group, statewide, often contains an unusual mineral assemblage consisting of palygorskite and sepiolite (mixed with other clay minerals), phosphate minerals, and dolomite. Although dolomite is not an uncommon mineral, some of the types present in the Hawthorn are poorly understood.

24) Phosphate is present throughout the sediments of the Hawthorn Group, constituting one of the primary lithologic parameters for this unit. In peninsular Florida, the occurrence of nonphosphatic lithologies is not common but does occur. However, in the eastern panhandle non-phosphatic, very clayey sediments are quite common. Phosphate is usually present as sand-sized to pebble-sized grains in concentrations ranging from less than 1 percent to greater than 50 percent. The average content is generally between 2 and 10 percent.

Economically important phosphate deposits are recognized in limited areas of northern and central Florida. Hard rock phosphates are also found in west-central Florida.

25) Palygorskite and sepiolite are not generally considered common clay minerals. The occurrence of these clays in association with dolosilts and phosphate suggests unusual depositional environments for the Miocene sediments in the southeastern United States. These clays occur throughout the Hawthorn Group in association with variable amounts of smectite, illite and, in some cases, kaolinite.

26) Dolomite is the most common carbonate component of the Hawthorn Group throughout much of Florida. Replacement dolomite and dolosilts are the predominant types. Replacement dolomite is the result of dolomitization of an original limestone. Dolosilts, on the other hand, resulted not only from the replacement of pre-existing fine grained carbonate, but also may be precipitated under a variety of conditions.

27) The Alachua Formation and its relationship to the Hawthorn Group has long been debated. The present author believes the Alachua is a weathered and/or reworked residuum of the Hawthorn Group.

28) Carbonate deposition dominated the Florida Plateau prior to Miocene time. During the Miocene a flood of siliciclastic sediments intermixed with and spilled over the carbonate environments. The siliciclastics filled the Gulf Trough and entered the depositional environments of Florida. This great influx of siliciclastics was possibly due to renewed uplift in the southern Apalachians.

29) The geologic history of the Hawthorn Group is directly related to the fluctuations of sea level throughout the Miocene. The highest sea levels were reached in the Middle Miocene during the deposition of the Coosawhatchie. During low stands of sea level, terrestrial vertebrate faunas migrated and developed on the exposed land.

30) The Miocene sediments of Florida were deposited in a series of complex depositional environments, resulting in the complex lithostratigraphic nature of the Hawthorn Group. The sediments of the Hawthorn Group of northern Florida were deposited in shallow water to limited supratidal environments. This is based on the molluskan fauna (molds), the occurrence of intraclasts, crossbedding,

and mudcracks. As mentioned above, the deepest water environment (still shallow) occurred during Coosawhatchie Formation deposition when the sea level was at its maximum.

In southern Florida, a carbonate bank environment existed throughout the time of deposition of the Arcadia. Water depths and siliciclastic supply increased to the east. As sea level rose during the Middle Miocene the carbonate bank environment was overrun by siliciclastics during the deposition of the Peace River Formation. The Bone Valley Member of the Peace River Formation was deposited in shallow water environments ranging from high energy nearshore to quieter water lagoons.

Hawthorn deposition during the Miocene in the eastern panhandle was limited to the late Early Miocene Torreya Formation. The depositional environment suggested by Weaver and Beck (1977) is a tidally influenced lagoon.

31) Gamma-ray logs provide an important tool for the correlation and interpretation of the Hawthorn sediments throughout Florida. The Hawthorn Group, in general, has a unique, identifiable gamma-ray signature. It has significantly higher (more intense) peaks than the overlying and underlying units, with gamma-ray intensities that vary from less than 50 cps to greater than 500 cps. Within each region of the state, signatures are characteristic and correlate well with the formational breakdown of the group.

CONCLUSIONS

The Hawthorn Group of the southeastern Coastal Plain is an unusual and complex unit. The complex lithostratigraphy of the strata indicates that the Hawthorn should be described as a group, rather than retaining the former formation status. The Hawthorn is formally raised herein to group status in Florida and is subdivided regionally into its component formations.

Regionally, the Hawthorn Group shows significant variation. As a result, the formational subdivision of the group is different for the northern and southern peninsula and for the eastern panhandle areas of Florida. The formations of the group in northern Florida are, in ascending order: the Penney Farms; the Marks Head; the Coosawhatchie, including its Charlton Member; and the Statenville. In southern Florida the units are, in ascending order: the Arcadia Formation with its Tampa and Nocatee Members; and the Peace River Formation, with its Bone Valley Member. The group in the eastern panhandle is represented by the Torreya Formation, with its Dogtown and Sopchoppy Members.

The formational names are, with the exception of the Torreya, new names to Florida stratigraphy. The Marks Head, Coosawhatchie and Statenville are names extended into Florida from Georgia, while the Penney Farms, Arcadia and Peace River are new names proposed here. The use of the Charlton, Tampa and Bone Valley names as members represents a reduction from formational status for these units. This demotion is justified by their limited areal extent, lithologies and stratigraphic relationships with the formations of which they are members.

The lithostratigraphic units of the Hawthorn Group are related by the occurrence of unusual mineralogies (including phosphate, palygorskite and sepiolite clay minerals, dolomite and opaline cherts), color and stratigraphic position. The occurrence of the unusual mineral suite is suggestive of a unique set of environmental conditions present during the deposition of the Hawthorn Group.

Further refinement and definition of the concept of the Hawthorn Group and its component formations will occur as new data become available. A better understanding of the framework of the group will assist in determining the conditions and processes responsible for the deposition of the unusual mineral suite associated with the Hawthorn sediments.

REFERENCES

Altschuler, Z.S., and Young, E.J., 1960, Residual origin of the "Pleistocene" sand mantle in central Florida uplands and its bearing on marine terraces and Cenozoic uplift: U.S. Geological Survey, Professional Paper 400-B, p. B202-B207.

_______________, Cathcart, J.B., and Young, E.J., 1964, Geology and geochemistry of the Bone Valley Formation and its phosphate deposits, west central Florida (Geological Society of America Annual Meeting Guidebook, field trip #6): Geological Society of America 1964 Meeting, 68 p.

Armstrong, J.R., Brown, M.P., and Wise, S.W., Jr., 1985, The geology of the Floridan aquifer system in eastern Martin and St. Lucie Counties, Florida, Southeastern Geology, v. 26, p. 21-38.

Assefa, G., 1969, Mineralogy and petrology of selected rocks from the Hawthorn Formation, Marion and Alachua Counties, Florida: (M.S. thesis), Gainesville, University of Florida, 81 p.

Badiozamani, K., 1973, The Dorag dolomization model - application to the Middle Ordovician of Wisconsin: Journal of Sedimentary Petrology, v. 43, p. 965-984.

Banks, J.E., and Hunter, M.E., 1973, Post-Tampa, pre-Chipola sediments exposed in Liberty, Gadsden, Leon, and Wakulla Counties, Florida: Trans., Gulf Coast Association Geological Societies v. 23, p. 355-363.

Bentor, Y.K., 1980, Phosphorites - the unsolved problems *in* Bentor, Y.K., ed., Marine Phosphorites -geochemistry, occurrence and genesis: Society of Economic Paleontologists and Mineralogists Special Publication 29, p. 3-18.

Bergendal, M.H., 1956, Stratigraphy of parts of DeSoto and Hardee Counties: U.S. Geological Survey Bulletin 1030-B, 33 p.

Bishop, E.W., 1956, Geology and ground water resources of Highlands County, Florida: Florida Geological Survey, Report of Investigation 15, 115 p.

Blow, W.H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy, *in* Bronnimann, P. and Renz, H.H. (eds.), Proceedings First Int. Conf. Planktonic Microfossils (Geneva, 1967): Leiden, Holland, E.J. Brill, p. 199-421.

Brooks, H.K., 1966, Geological history of the Suwannee River: Southeastern Geological Society, 12th Annual Field Conference Guidebook, p. 37-45.

_______________, 1967, Miocene-Pliocene problems of peninsular Florida: Southeastern Geological Society, 13th Field Trip Guidebook, p. 1-2.

_______________, Gremillion, L.R., Olson, N.K., and Puri, H.S., 1966, Geology of the Miocene and Pliocene Series in the north Florida-south Georgia area: Southeastern Geological Society, 12th Annual Field Conference, 94 p.

Burnett, W.C., 1977, Geochemistry and origin of phosphorite deposits from off Peru and Chile: Geological Society of America Bulletin v. 88, p. 813-823.

Burnett, W.C., Veeh, V.H., and Soutar, A. 1980, U-series, oceanographic and sedimentary evidence in support of recent formation of phosphate nodules off Peru: *in* Bentor, Y.K. ed. Marine Phosphorites -geochemistry, occurrence and genesis, Society of Economic Paleontologists and Mineralogists Special Publication 29, p. 61-72.

Carr, W.J., and Alverson, D.C., 1959, Stratigraphy of middle Tertiary rocks in parts of west central Florida: U.S. Geological Survey Bulletin 1092, 111 p.

Cathcart, J.B., 1950, Notes on the land pebble phosphate deposits of Florida: *in* Proceedings, Symposium on mineral resources of the southeastern United States: Knoxville, University of Tennessee Press, p. 132-151.

_______________, 1963a, Economic geology of the Keysville Quadrangle, Florida: U.S. Geological Survey Bulletin 1128, 82 p.

_______________, 1963b, Economic geology of the Chicora Quadrangle, Florida: U.S. Geological Survey Bulletin 1162-A, 66 p.

_______________, 1964, Economic geology of the Lakeland Quadrangle, Florida: U.S. Geological Survey Bulletin 1162-G, 128 p.

_______________, 1966, Economic geology of the Fort Meade Quadrangle, Polk and Hardee Counties, Florida: U.S. Geological Survey Bulletin 1207, 97 p.

_______________, and Davidson, D.F., 1952, Distribution and origin of phosphate in the Land Pebble Phosphate District of Florida: U.S. Geological Survey TEI-212, 14 p.

_______________, and McGreevy, L.J., 1959, Results of geologic exploration by core drilling, 1953 Land Pebble Phosphate District, Florida: U.S. Geological Survey Bulletin 1046-K, 77 p.

Chen, C.S., 1965, The regional lithostatigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geological Survey Bulletin 45, 105 p.

Clark, D.S., 1972, Stratigraphy, genesis, and economic potential of the southern part of the Florida Land Pebble Phosphate Field: (Ph.D. dissertation): University of Missouri-Rolla, 182 p.

Colton, R.C., 1978, The subsurface geology of Hamilton County, Florida with emphasis on the Oligocene age Suwannee Limestone (M.S. thesis): Tallahassee, Florida State University, 185 p.

Cooke, C.W., 1936, Geology of the Coastal Plain of South Carolina: U.S. Geological Survey Bulletin 867, 196 p.

_______________, 1943, Geology of the Coastal Plain of Georgia: U.S. Geological Survey Bulletin 941, 121 p.

_______________, 1945, Geology of Florida: Florida Geological Survey Bulletin 29, 339 p.

_______________, and Mossom, S., 1929, Geology of Florida: Florida Geological Survey Annual Report 20, p. 29-228.

Dall, W.H., 1896, Descriptions of Tertiary fossils from the Antillean region: U.S. Natural Museum Proceedings, v. XIX, n. 1110, p. 303-305.

_______________, and Harris, G.D., 1892, Correlation papers-Neocene: U.S. Geological Survey Bulletin 84, 349 p.

Day, D.T., 1886, Phosphate rock: U.S. Geological Survey, Mineral Resources of the United States for 1885, p. 445-454.

Eldridge, G.H., 1893, Preliminary sketch of the phosphates of Florida: American Institute of Mining Engineers, v. xxi, p. 196-231.

Espenshade, G.H., 1958, Geologic features of areas of abnormal radioactivity south of Ocala, Marion County, Florida: U.S. Geological Survey Bulletin 1046-J, 14 p.

_______________, and Spencer, C.W., 1963, Geology of phosphate deposits of northern peninsular Florida: U.S. Geological Survey Bulletin 1118, 115 p.

Folk, R.L. and Land, L.S., 1975, Mg/Ca ratio and salinity, Two controls over the crystallization of dolomite: American Association of Petroleum Geologists Bulletin, v. 59, p. 60-68.

Freas, D.H. and Riggs, S.R., 1968, Environments of phosphorite deposition in the Central Florida Phosphate District, *in* Proceedings, 4th Forum on Industrial Minerals: Texas Bureau of Economic Geology, p. 117-128.

Gardner, J., 1926, The molluscan fauna of the Alum Bluff Group of Florida: U.S. Geological Survey Professional Paper 142-A, p. 1-79.

Gebelein, C.D., Steinen, R.P., Garrett, P., Hoffman, E.J., Queen, J.M., and Plummer, L.N., 1980, Subsurface dolomitization beneath the tidal flats of central west Andros Island, Bahamas, *in* D. Zenger, J. Dunham, and R. Ethington, eds., Concepts and models of dolomitization: Society of Economic Paleontologists and Mineralogists Special Publication 28, p. 31-50.

Gibson, T.G., 1967, Stratigraphy and paleoenvironment of the phosphatic Miocene strata of North Carolina: Geological Society of America Bulletin, v. 78, p. 631-650.

________________, 1982, Depositional framework and paleoenvironments of Miocene strata from North Carolina to Maryland: *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 1-22.

Gilboy, A.E., 1983, Correlation between lithology and natural gamma logs within the Alafia Basin of the Southwest Florida Water Management District: Southwest Florida Water Management District, 20 p.

Goodell, H.G. and Yon, J.W., Jr., 1960, The regional lithostratigraphy of the post-Eocene rocks of Florida: Southeastern Geological Society, 9th Field Trip Guidebook, p. 75-113.

Gremillion, L.R., 1965, The origin of attapulgite in the Miocene strata of Florida and Georgia: (Ph.D. dissertation), Tallahassee, Florida State University, 139 p.

Grim, R.E., 1968, Clay Mineralogy (2nd edition): New York, McGraw-Hill Book Company, 596 p.

Hall, R.B., 1983, General geology and stratigraphy of the southern extension of the Central Florida Phosphate District (Geological Society of America Southeast Section field trip guidebook): Southeastern Geological Society, p. 1-27.

Hathaway, J.C., 1979, Clay Minerals: *in* R. Burns, ed. Marine Minerals v. 6: Reviews in Mineralogy p. 123-150.

Hawes, G.W., 1882, On a phosphatic sandstone from Hawthorn in Florida: *in* Proceedings of the U.S. Natural Museum, v. V, p. 46-48.

Hendry, C.W., Jr., and Sproul, C.R., 1966, Geology and groundwater resources of Leon County, Florida: Florida Geological Survey Bulletin 47, 178 p.

________________, and Yon, J.W., Jr., 1967, Stratigraphy of Upper Miocene Miccosukee Formation, Jefferson and Leon Counties, Florida: American Association of Petroleum Geologists Bulletin, v. 51, p. 250-256.

Heron, S.D., Jr. and Johnson, H.S., Jr., 1966, Clay mineralogy stratigraphy and structural setting of the Hawthorn Formation, Coosawhatchie District, South Carolina: Southeastern Geology, v. 7, p. 51-63.

Herrick, S.M. and Vorhis, R.C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Department of Mines, Mining and Geology Information Circular 25, 67 p.

Hetrick, J.H. and Friddell, M.S., 1984, Clay mineralogy of the Hawthorn Group: Georgia Geological Survey Open File Report 84-7, 91 p.

Hoenstine, R.W., 1984, Biostratigraphy of selected cores of the Hawthorn Formation in northeast and east-central Florida: Florida Bureau of Geology Report of Investigation 93, 68 p.

Hopkins, O.B., 1920, Drilling for oil in Florida: U.S. Geological Survey Press Bulletin, April, 1920.

Huang, Hui-Lun, 1977, Stratigraphic investigations of several cores from the Tampa Bay area, (M.S. thesis): Tampa, University of South Florida, 54 p.

Huddlestun, P.F., and Hunter, M.E., 1982, Stratigraphic revision of the Torreya Formation of Florida (Abs.), *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the southeastern United States, Proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 210.

Huddlestun, P.F., Hoenstine, R.W., Abbott, W.H., and Woosley, R., 1982, The stratigraphic definition of the Lower Pliocene Indian River beds of the Hawthorn in South Carolina, Georgia and Florida (Abs.), *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 184-185.

Huddlestun, P.F., A revision of the lithostratigraphic units of the Coastal Plain of Georgia: Georgia Geological Survey Bulletin, (in press).

Hunter, M.E., 1968, Molluscan guide fossils in Late Miocene sediments of southern Florida: Transactions, Gulf Coast Association of Geological Societies, v. 8, p. 439-450.

________________, and Wise, S.W., 1980a, Possible restriction and redefinition of the Tamiami Formation of South Florida: Points of Discussion (Abs.): Florida Scientist, v. 43, supplement 1, 42 p.

________________, and Wise, S.W., 1980b, Possible restriction and redefinition of the Tamiami Formation of South Florida: Points of further discussion: Miami Geological Society Field Guide 1980, p. 41-49.

________________, and Huddlestun, P.F., 1982, The biostratigraphy of the Torreya Formation of Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 211-223.

Isphording, W.C., 1963, A study of the heavy minerals from the Hawthorn Formation and overlying sands exposed at the Devil's Millhopper, Alachua County, Florida: (M.S. thesis): Gainesville, University of Florida, 31 p.

Johnson, L.C., 1885, Phosphatic rocks of Florida: Science., v. V, p. 396.

________________, 1888, Structure of Florida: American Journal of Science, 3rd Series, v. 36, p. 230-236.

Johnson, R.A., 1984, Stratigraphic analysis of geophysical logs from water wells in peninsular Florida: St. Johns River Water Management District Technical Publication SJ84-16, 76 p.

Kazakov, A.V., 1937, The phosphorite facies and the genesis of phosphorites: *in* Geological Investigations of Agricultural Ores, Transactions, Science Institute Fert. and Insecto-Fungicides, v. 142, p. 95-113.

Ketner, K.B. and McGreevy, L.J., 1959, Stratigraphy of the area between Hernando and Hardee Counties, Florida: U.S. Geological Survey Bulletin 1074-C, 75 p.

Kerr, P.F., 1937, Attapulgus clay: American Minerals v. 22, 5, p. 534-550.

King, K.C., 1979, Tampa Formation of peninsular Florida, a formal definition, (M.S. thesis), Tallahassee, Florida State University, 83 p.

________________, and Wright, R., 1979, Revision of the Tampa Formation, west central Florida: Transactions, Gulf Coast Association of Geological Societies, v. 29, p. 257-262.

Kost, J., 1887, First report of the Florida Geological Survey, 33 p.

Leroy, R.A., 1981, The mid-Tertiary to recent lithostratigraphy of Putnam County, Florida State University, 179 p.

Leve, G.W., 1965, Ground water in Duval and Nassau Counties, Florida: Florida Geological Survey, Report of Investigation 43, 91 p.

Liu, J., 1978, Petrography of the Ballast Point, Brandon and Duette drill cores, Hillsborough and Manatee Counties, Florida, (M.S. thesis): Gainesville, University of Florida, 55 p.

MacFadden, B.J., 1980, An Early Miocene land mammal (Oreodonta) from a marine limestone in northern Florida: Journal of Paleontology, v. 54, p. 93-101.

_______________, and Webb, S.D., 1982, The succession of Miocene (Arikareean through Hemphillian) terrestrial mammal localities and faunas in Florida, *in* Scott, T.M., and Upchurch, S.B., eds, Miocene of the Southeastern United States, proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 186-199.

MacNeil, F.S., 1944, Oligocene stratigraphy of the southeastern United States: American Association of Petroleum Geologists Bulletin 28, p. 1313-1354.

Mansfield, W.C., 1939, Notes on the upper Tertiary and Pleistocene mollusks of peninsular Florida: Florida Geological Survey Bulletin 18, 75 p.

Matson, G.C., 1915, Phosphate deposits of Florida: U.S. Geological Survey Bulletin 604, 101 p.

_______________, and Clapp, F.G., 1909, A preliminary report of the geology of Florida with special reference to the stratigraphy: Florida Geological Survey 2nd Annual Report, p. 25-173.

_______________, and Sanford, S., 1913, Geology and ground water of Florida: U.S. Geological Survey Water Supply Paper 319, 444 p.

McClellan, G.H., 1962, Identification of clay minerals from the Hawthorn Formation, Devil's Millhopper, Alachua County, Florida, (M.S. thesis): Gainesville, University of Florida, 119 p.

_______________, 1964, Petrology of attapulgus clay in north Florida and southwest Georgia: (Ph.D. dissertation): Urbana, University of Illinois, 119 p.

McFadden, M., 1982, Petrology of porcellinities in the Hawthorn Formation, Hamilton County, Florida, (M.S. thesis): Tampa, University of South Florida, 113 p.

_______________, Upchurch, S.B., and Strom, R.N., 1983, Modes of silicification of the Hawthorn Formation in north Florida: Geological Society of America Abstracts with Programs, Southeast Section, v. 15.

Meisburger, E.P. and Field, M.E., 1976, Neogene sediments of Atlantic Inner Continental Shelf off northern Florida: American Association of Petroleum Geologists Bulletin, v. 60, p. 2019-2037.

Miller, J.A., 1978, Geologic and geophysical logs from Osceola National Forest, Florida: U.S. Geological Survey, Open File Report 78-799, 103 p.

_______________, 1982, Structural and sedimentary setting of phosphorite deposits in North Carolina and northern Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, proceedings of the symposium: Florida Bureau of Geology Speciai Publication 25, p. 162-182.

Millot, G., 1970, Geology of Clays: New York, Springer verlag, 429 p.

Missimer, T.M., 1978, The Tamiami Formation-Hawthorn Formation contact in southwest Florida: Florida Scientist, v. 41, p. 31-38.

________________, and Gardner, R.A., 1976, High resolution seismic reflection profiling for mapping shallow aquifers in Lee County, Florida: U.S. Geological Survey Water Resource Investigation 76-45, 29 p.

________________, and Banks, R.S., 1982, Miocene cyclic sedimentation in western Lee County, Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, Proceedings of the symposium: Florida Bureau of Geology Special Publication 25, p. 285-298.

Mitchell, L.M., 1965, Petrology of selected carbonate rocks from the Hawthorn Formation, Devil's Millhopper, Alachua County, Florida, (M.S. thesis), Gainesville, University of Florida, 53 p.

Mossom, S., 1925, A preliminary report on the limestone and marls of Florida: Florida Geological Survey Annual Report 16, p. 28-203.

________________, 1926, A review of the structure and stratigraphy of Florida with special reference to the petroleum possibilities: Florida Geological Survey Annual Report 17, p. 169-275.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, n. 5, p. 841-875.

Ogden, G.M., Jr., 1978, Depositional environment of the fuller's earth clays of northwest Florida and southwest Georgia, (M.S. thesis): Tallahassee, Florida State University, 74 p.

Parker, G.G., 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne Aquifer: Journal of the American Water Works Association, v. 43, pt. 2, p. 817-834.

________________, and Cooke, C.W., 1944, Late Cenozoic geology of southern Florida with a discussion of ground water: Florida Geological Survey, Bulletin 27, 119 p.

________________, Ferguson, G.E., and Love, S.K., 1955, Water resources of southeastern Florida: U.S. Geological Survey Water Supply Paper 1255, 965 p.

Peacock, R.S., 1981, The post-Eocene stratigraphy of southern Collier County, Florida, (M.S. thesis): Tallahassee, Florida State University, 120 p.

Peck, D.M., Slater, D.H., Missimer, T.M., Wise, S.W., Jr., and O'Donnell, T.H., 1979, Stratigraphy and paleoecology of the Tamiami Formation in Lee and Hendry Counties, Florida: Transactions, Gulf Coast Association of Geological Societies, v. 29, p. 328-341.

Penrose, R.A.F., Jr., 1888, Nature and origin of the deposits of phosphate of lime: U.S. Geological Survey Bulletin 46, 143 p.

Pirkle, E.C., Jr., 1956a, Pebble phosphate of Alachua County, Florida, (Ph.D. dissertation): Cincinnati, University of Cincinnati, 203 p.

________________, 1956b, The Hawthorne and Alachua formations of Alachua County, Florida: Florida Scientist, v. 19, p. 197-240.

________________, 1957, Economic considerations of pebble phosphate deposits of Alachua County, Florida: Economic Geology, v. 52, p. 354-373.

Pirkle, E.C., Yoho, W.H., and Allen, A.T., 1965, Hawthorne, Bone Valley and Citronelle sediments of Florida: Florida Scientist, v. 28, p. 7-58.

________________, Yoho, W.H., and Webb, S.D., 1967, Sediments of the Bone Valley Phosphate District of Florida: Economic Geology, v. 67, p. 237-261.

Poag, W., 1972, Planktonic foraminifera of the Chickasawhay Formation: U.S. Gulf Coast: Micropaleontology, v. 18, p. 257-277.

Prasad, S., 1983, Microsucrosic dolomite from the Hawthorn Formation (Miocene) of Florida: Distribution and development, *in* Annual Report 1983 Comparative Sedimentology Laboratory, Fisher Island, Rosenstiel School of Marine and Atmospheric Sciences: Miami, University of Miami, p. 58-65.

________________, 1985, Microsucrosic dolomite from the Hawthorn Formation (Miocene) of Florida: Distribution & Development, (M.S. thesis): Miami, University of Miami, 124 p.

Pressler, E.D., 1947, Geology and occurrence of oil in Florida: America Association of Petroleum Geologists Bulletin, v. 31, p. 1851-1862.

Puri, H.S., 1953, Contribution to the study of the Miocene of the Florida panhandle: Florida Geological Survey Bulletin 36, 345 p.

Puri, H.S., and Vernon, R.O., 1964, Summary of the geology of Florida: Florida Geological Survey, Special Publication n. 5 (revised), 312 p.

Reik, B.A., 1980, The Tertiary stratigraphy of Clay County, Florida with emphasis on the Hawthorn Formation, (M.S. thesis): Florida State University, 169 p.

________________, 1982, Clay mineralogy of the Hawthorn Formation in northern and eastern Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, Proceedings of the symposium: Florida Bureau of Geology, Special Publication 25, p. 247-250.

Reynolds, W.R., 1962, The lithostratigraphy and clay mineralogy of the Tampa-Hawthorn sequence of peninsular Florida, (M.S. thesis): Tallahassee, Florida State University, 126 p.

Riggs, S.R., 1967, Phosphorite stratigraphy, sedimentation and petrology of the Noralyn Mine, Central Florida Phosphate District, (Ph.D. dissertation): Missoula, University of Montana, 268 p.

________________, 1979a, Petrology of the Tertiary phosphorite system of Florida: Economic Geology, v. 74, p. 195-220.

________________, 1979b, Phosphorite sedimentation in Florida - a model phosphogenic system: Economic Geology, v. 74, p. 285-314.

________________, 1980, Intraclasts and pellet phosphortie sedimentation in the Miocene of Florida: Journal of Geology, Geological Society of London, v. 137, p. 741-748.

________________, 1984, Paleoceanographic model of Neogene phosphorite deposition, U.S. Atlantic continental margin: Science, v. 223, n. 4632, p. 123-131.

________________, and Freas, D.H., 1965, Stratigraphy and sedimentation of phosphorite in the Central Florida Phosphorite District: Society on Mining Engineers, American Institute of Mining Engineers Preprint #65H84, 17 p.

Schmidt, W., 1984, Neogene stratigraphy and geologic history of the Apalachicola Embayment, Florida: Florida Geological Survey Bulletin 58, 146 p.

Scott, L.E. 1981, Borehole mining of phosphate ores: U.S. Bureau of Mines, Open File Report 138-82, 215 p.

Scott, T.M., 1981, The paleoextent of the Miocene Hawthorn Formation in peninsular Florida (abs): Florida Scientist, v. 44, Supplement 1, p. 42.

________________, 1982, A comparison of the cotype localities and cores of the Miocene Hawthorn Formation in Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, Proceedings of the symposium: Florida Bureau of Geology Special Publication 25, p. 237-246.

_______________, 1983, The Hawthorn Formation of northeast Florida: Part I - The geology of the Hawthorn Formation of northeast Florida: Florida Bureau of Geology, Report of Investigation 94, p. 1-43.

_______________, and Hajishafie, M., 1980, Top of the Floridan Aquifer in the St. Johns River Water Management District: Florida Bureau of Geology, Map Series 95.

_______________, and MacGill, P.M., 1981, The Hawthorn Formation of central Florida: Part I - Geology of the Hawthorn Formation in central Florida: Florida Bureau of Geology, Report of Investigation 91, p. 1-32.

Sellards, E.H., 1910, A preliminary paper on the Florida phosphate deposits: Florida Geological Survey Annual Report 3, p. 17-42.

_______________, 1913, Origin of the hard rock phosphate of Florida: Florida Geological Survey Annual Report 5, p. 24-80.

_______________, 1914, The relation between the Dunnellon Formation and the Alachua clays of Florida: Florida Geological Survey Annual Report 6, p. 161-162.

_______________, 1915, The pebble phosphates of Florida: Florida Geological Survey Annual Report 7, p. 29-116.

_______________, 1919, Geology of Florida: Journal of Geology, v. 27, 4, p. 286-302.

Sever, C.W., Cathcart, J.B., and Patterson, S.H., 1967, Phosphate deposits of south-central Georgia and north-central peninsular Florida: Georgia Division of Conservation, Project Report 7, South Georgia Minerals Program, 62 p.

Sheldon, R.P., 1980, Episodicity of phosphate deposition and deep ocean circulation - a hypothesis, *in* Bentor, Y.K., ed., Marine phosphorites - geochemistry, occurrence, genesis: Society of Economic Paleontologists and Mineralogists Special Publication 29, p. 239-248.

Smith, E.A., 1881, Geology of Florida: American Journal of Science, 3rd Series, V. XXI, p. 292-309.

_______________, 1885, Phosphatic rocks of Florida: Science, v. V, p. 395-96.

Sproul, C.R., Boggess, D.H., and Woodard, H.J., 1972, Saline water intrusion from deep artesian sources in the McGregor Isles area of Lee County: Florida Bureau of Geology, Information Circular 75, 30 p.

Stringfield, V.T., 1933, Ground water in the Lake Okeechobee area, Florida: Florida Geological Survey, Report of Investigation 2, 31 p.

Strom, R.N., Upchurch, S.B., and Rosenzweig, A., 1981, Paragenesis of "boxwork-geodes," Tampa Bay, Florida: Sedimentary Geology, v. 30, p. 275-289.

_______________, and Upchurch, S.B., 1983, Palygorskite (attapulgite)-rich sediments in the Hawthorn Formation: A product of alkaline lake deposition? Central Florida Phosphate District: Geological Society of America Field Trip Guidebook, Southeast Section meeting, Tallahassee, Florida, p. 73-82.

_______________, and Upchurch, S.B., 1985, Palygorskite distribution and silicification in the phosphatic sediments of central Florida, *in* Cathcart, J.B., and Scott, T.M., eds., Florida land-pebble phosphate district, (Geological Society of America fieldtrip guidebook, Annual Meeting), Orlando, Florida, p. 68-75.

Teleki, P.G., 1966, Differentiation of materials formerly assigned to the "Alachua Formation," (M.S. thesis): Gainesville, University of Florida, 101 p.

Toulmin, L.D., 1955, Cenozoic geology of southeastern Alabama, Florida and Georgia: American Association of Petroleum Geologists Bulletin, v. 39, p. 207-235.

Upchurch, S.B., Strom, R.N., and Nuckles, G.M., 1982, Silicification of Miocene rocks from central Florida, *in* Scott, T.M., and Upchurch, S.B., eds., Miocene of the Southeastern United States, Proceedings of the symposium: Florida Bureau of Geology Special Publication 25, p. 251-284.

_______________, and Lawrence, F., 1984, Impact of ground-water geochemistry on sinkhole development along a retreating scarp, *in* B. Beck, ed., Sinkholes: Their geology, engineering, and environmental impact: Netherlands, A.A. Balkema Publishers, p. 23-28.

U.S. Geological Survey, 1966, Lexicon of Geologic names: U.S. Geological Survey Bulletin 1200.

Vail, P.R. and Mitchum, R.M., Jr., 1979, Global cycles of relative changes of sea level from seismic stratigraphy, *in* Watkins, J.S., Montadert, L., and Dickerson, P.W., eds., Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Mem. 29, p. 469-472.

Vaughan, T.W. and Cooke, C.W., 1914, Correlation of the Hawthorn Formation: Washington Academy of Science Journal, v. 4, n. 10, p. 250-253.

Veatch, O. and Stephenson, L.W., 1911, Geology of the coastal plain of Georgia, Bulletin 26, 466 p.

Vernon, R.O., 1951, Geology of Citrus and Levy counties, Florida: Florida Geological Survey, Bulletin 33, 256 p.

Weaver, C.E., and Beck, K.C., 1977, Miocene of the southeastern United States: A model for chemical sedimentation in a peri-marine environment: Sedimentary Geology, v. 17, p. 1-234.

_______________, 1982, Environmental implications of palygorskite (attapulgite) in Miocene of the southeastern United States, *in* Arden, D., Beck, B., and Morrow, E., eds., Second symposium of the geology of the southeastern Coastal Plain: Georgia Geological Survey, Information Circular 53, p. 118-125.

Webb, S.D. and Crissinger, D.B., 1983, Stratigraphy and vertebrate paleontology of the central and southern Phosphate District of Florida, *in* Central Florida Phosphate District (Geological Society of America, Southeast Section Field Trip Guidebook): p. 28-72.

Wedderburn, L.A., Knapp, M.S., Waltz, D.P., and Burns, W.S., 1982, Hydrogeologic reconnaissance of Lee County, Florida: South Florida Water Management District Technical Publication 82-1, 192 p.

Williams, G.K., 1971, Geology and geochemistry of the sedimentary phosphate deposits of northern peninsular Florida, (Ph.D. dissertation): Tallahassee, Florida State University, 124 p.

Wilson, W.E., 1977, Ground water resources of DeSoto and Hardee Counties, Florida: Florida Bureau of Geology, Report of Investigation 83, 102 p.

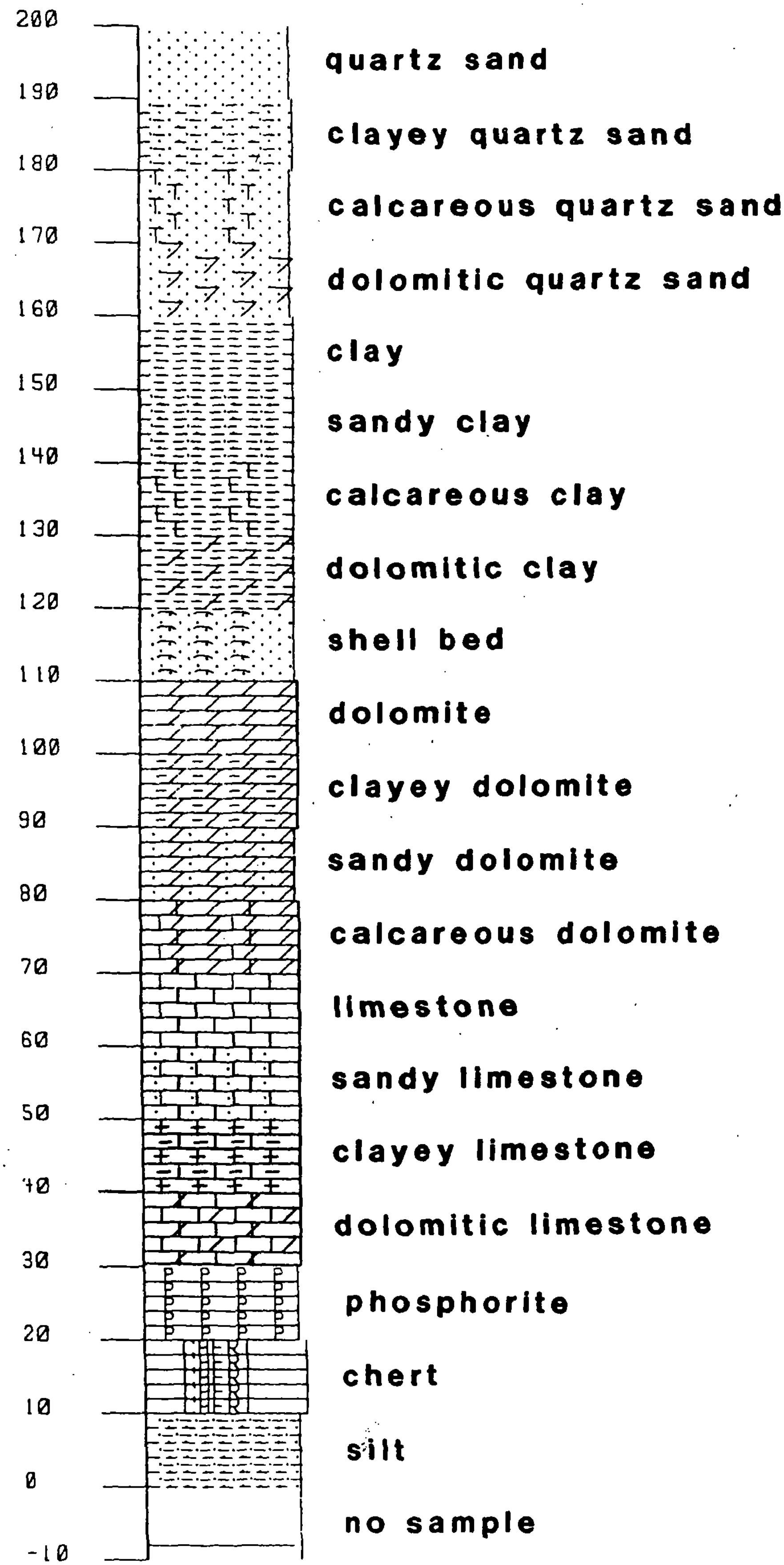
Yon, J.W., Jr., 1953, The Hawthorn Formation (Miocene) between Chattahoochee and Ellaville, Florida, (M.S. thesis): Tallahassee, Florida State Universtiy, 94 p.

_______________, 1966, Geology of Jefferson County, Florida: Florida Geological Survey, Bulletin 48, 115 p.

Zenger, D.H., and Dunham, J.B., 1980, Concepts and models of dolomitization - an introduction, *in* Zenger, D.; Dunhan, J., and Ethington, J., eds., Concepts and models of dolomitization: Society of Economic Paleontologists and Mineralogists Special Publication 28, p. 1-10.

APPENDIX A

Lithologic legend for stratigraphic columns.



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FLORIDA GEOLOGICAL SURVEY SPECIAL PUBLICATION NO. 32

FLORIDA'S GROUND WATER QUALITY MONITORING PROGRAM

HYDROGEOLOGICAL FRAMEWORK

COORDINATED BY
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LETTER OF TRANSMITTAL

Florida Geological Survey
Tallahassee
June 1991

Governor Lawton Chiles, Chairman
Florida Department of Natural Resources
Tallahassee, Florida 32301

Dear Governor Chiles:

The Florida Geological Survey, Division of Resource Management, Department of Natural Resources, is publishing, as its Special Publication No. 32, Florida's Ground Water Quality Monitoring Program: Hydrogeologic Framework. This publication is the first in a series which will present the results of the ground water quality network program established by the 1983 Water Quality Assurance Act (Florida Statutes, Chapter 403.063). It is primarily a series of maps which provide the basic hydrogeologic conditions present within the principal aquifers of Florida. These results can be used by state and local governments, planners, and developers for land-use planning, conservation, and protection of Florida's valuable water resources.

Respectfully yours,

Walter Schmidt, Ph.D., P.G.
State Geologist and Chief
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Cover Illustration
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Florida's population growth creates ever-increasing pressures on fragile water resources. This drawing illustrates many of the complex relationships that exist between a Florida community and the environment which sustains it. Water for various uses is withdrawn from subsurface limestones which are extremely porous and permeable. Ground water which resides in these limestones is naturally protected from various types of contaminants by a widespread clayey confining layer. The situation is complicated by the presence of discontinuous carbonate lenses and fractures within the confining layer. Limestone is vulnerable to extensive dissolution leading to the development of sinkholes which may breach the confining unit in the process of their formation. This same dissolutional process results in the formation of the large springs, highly prized features of Florida's environment, from which large amounts of ground water discharge constantly. The spring pictured here includes as part of its recharge mechanism, the newly formed sinkhole, ostensibly distant from it. The surficial sands and clayey sands which blanket the confining layer are subject to major impacts resulting from the activities of man. Subsurface storage tanks will be buried within them, municipal solid waste will be disposed into them and locally, small domestic wells may be drilled into them where their permeability and porosity make them a viable surficial aquifer. At the same time, precipitation moving down into these shallow materials may locally enter sinkholes or fractures within the confining layer, contributing to recharge of the underlying limestone aquifer system.

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INTRODUCTION

By

Gary Maddox and Jacqueline M. Lloyd, P.G. #74

Usable fresh water is Florida's most important natural resource. Pressure on this resource comes from rapid land use changes associated with urban and agricultural development. In order to insure sufficient fresh water for the state's current and future needs, this resource must be defined, protected and conserved.

As of 1980, 87% of Florida's public water supply came from subsurface aquifers. The remaining 13% was extracted from surface water sources, such as rivers and lakes. Most surface water requires considerably more treatment than ground water before use as a potable water source (Fernald and Patton, 1984). Florida's ground-water and surface-water systems are intimately connected. Lake and river waters recharge underlying aquifers at times when surface-water levels are higher than water-table elevations. Conversely, ground water flows into rivers and lakes through seepage and spring flow when water-table levels exceed surface-water levels. Where karst features, such as sinkholes, are well developed, there may be a direct connection between surface water and ground water. Shallow aquifers often have little or no protective, overlying aquitard or aquiclude. These common hydrogeologic conditions increase the risk of contamination of Florida's water supply.

Land-use planning must take hydrogeologic conditions into account. Whether through percolation or direct connection, polluted surface water can eventually contaminate ground water. Pesticides, herbicides and fertilizers from agricultural areas, metals and organics from urban stormwater runoff, and hydrocarbons from leaking storage tanks are all threats to Florida's aquifer systems.

In addition to these water quality considerations, land-use planning must also take into account water quantity. Excessive withdrawal of fresh water from an aquifer may lead to replacement of lighter, fresh water by denser, connate seawater. This is a problem in high volume ground-water withdrawal areas, such as in the vicinity of urban well fields. Excessive fresh water use in coastal areas may lead to the lateral intrusion of salt water from the sea.

Recharge areas where significant amounts of meteoric and surface water enter the aquifer are particularly sensitive to land uses. Some land uses may contribute contaminants to soil or surface waters or restrict the downward percolation of meteoric and surface waters. Protecting these areas from heavy development aids in the preservation of the quality and quantity of the ground-water supply.

Ground Water Quality Monitoring Program

The Florida legislature, acknowledging the need to protect our ground-water resources, passed the Water Quality Assurance Act in 1983. The legislature recognized that we must understand the impact of man's activities on our ground-water systems before we can determine appropriate protective measures. Thus, a portion of the Act required the Department of Environmental Regulation (DER) to "establish a ground-water quality monitoring network designed to detect or predict contamination of the state's ground-water resources" (Florida Statutes, Chapter 403.063). The Act required DER to work cooperatively with other federal and state agencies, including Florida's five water management districts (WMD's) (Figure 1), in the establishment of the network. The Florida Geological Survey (FGS) and the Water Resources Division of the U.S. Geological Survey provided technical support. In addition, several studies were funded through the State University System. Appendix 1 contains contact information for these agencies. Appendix 2 contains a list of reports and publications resulting from these efforts.

The major goals of the Ground Water Quality Monitoring Program are:

1. To establish the baseline ground-water quality of major aquifer systems in the state;
2. To detect and predict changes in ground-water quality resulting from the effects of various land uses and potential sources of contamination;
3. To disseminate water-quality data generated by the program to local governments and the public.

Hydrogeologic Map Production and Publication

To meet the goals set forth above, a hydrogeologic framework must first be defined. This publication is primarily a series of maps which portray the basic hydrogeologic conditions present within the principal aquifer systems of Florida. These maps were prepared by the water management districts, the FGS, and the DER.

Most maps were compiled on water management district base maps. Specific map coverage varied between districts. Single-topic maps may not be comparable between districts because they were not initially produced as a cooperative effort. For example, contour intervals may differ, making edge-matching impractical. The maps for each district generally include:

1. Isopach and structure contour maps of the surficial, intermediate and Floridan aquifer systems;
2. Isopach and structure contour maps of beds acting as aquitards and aquicludes;
3. Areas where the Floridan aquifer system is at or near the surface and areas where it is under water-table conditions;
4. Areas of recharge to the Floridan aquifer system;
5. Potentiometric surface of the Floridan aquifer system;
6. Areas of saltwater intrusion;
7. Areas of karst development;
8. Ground-water and surface-water basins.

Ground Water Quality Monitoring Network And Future Publications

The hydrogeologic framework defined by the maps in this publication provide the background necessary to establish the monitoring network, set priorities, and determine strategies for meeting the goals of the program.

The Ground Water Quality Monitoring Network is made up of three principal elements: two major subnetworks and one survey, each of which has unique monitoring priorities and goals. These elements are:

1. Background Network, designed to help define background ground-water quality through a network of approximately 1800 wells that tap all major potable aquifers within the state (Figure 2);
2. VISA (Very Intense Study Area) Network, designed to monitor the effects of various land usage on ground-water quality within specific aquifer systems in selected areas (Figure 3);
3. Private Well Survey, designed to analyze ground-water quality from 50 private drinking water wells in each of Florida's 67 counties. This survey is a joint effort between the Florida Department of Health and Rehabilitative Services (HRS) and the DER.

The water-quality data collected, analyzed, and evaluated through these elements will be published in separate volumes.

Background Network

A well in the Background Network is designed to monitor an area of the aquifer system which is representative of the general ground-water quality of a region. For this publication, a region is defined as constituting an area greater than or equal to the size of an average Florida county. It is further defined by aquifer system extent and, if possible, by ground-water basin. Background Network wells are actually used to define baseline rather than original background ground-water quality. Baseline differs from background in that it refers to current, representative regional water quality. Widespread changes in water quality associated with regional land uses may be present. Thus, Background Network water quality may differ from the original water quality that existed before there was measurable human impact on the aquifer system. Wells which indicate specific contamination sources are not included in the Background Network. The statewide distribution of Background Network wells is shown in Figure 2.

Before drilling of Background Network monitoring wells began, existing wells suitable for inclusion in the network were sought. An inventory of potentially useful existing monitoring sites was compiled by the U.S. Geological Survey and the water management districts. The following criteria were used to determine eligibility:

1. Depth of well and cased interval known;
2. Open hole interval taps only one aquifer or water-bearing zone;
3. Precise site location known;
4. Well owner cooperative;
5. Future accessibility for sampling granted;
6. History of the site (prior land use, previous sampling results) known.

Other non-mandatory, but desirable criteria include:

7. Site ownership by local, state or federal agency;
8. Prior water-quality data available;
9. Well diameter known;
10. Lithological and geophysical logs available;
11. Hydrogeologic information available.

To further aid in well selection and placement, the locations of potential and confirmed sources of ground-water contamination were determined. These included point sources such as locations of free-flowing wells, major landfills, injection and recharge wells, surface impoundments, industrial and hazardous waste generators, sewage treatment plants, and mining areas. Nonpoint sources included sewered versus septic areas, pesticide application (agricultural) areas, wastewater application areas, stormwater facilities and fresh water outfalls.

Over 1200 existing wells were initially selected for inclusion in the Background Network. Although optimal quality assurance and control could be more fully realized by drilling all monitoring wells expressly for use in the network, the associated costs prohibited such an approach.

Approximately 600 new wells were drilled for inclusion in the network. Depending on the hydrostratigraphy at each new site, a single well or cluster of wells was installed, allowing each major water-bearing zone to be separately monitored. Geological information was obtained at each site during drilling. A core from the uppermost significant confining bed was obtained from many sites for laboratory determination of permeability and lithologic description of the constituent sediments.

The initial sampling of each well in the network involved the measurement of a comprehensive set of field, chemical, and micro-biological parameters, as well as naturally-occurring radioactivity (Table 1). These analyses, combined with historical data, are used to estimate baseline ground-water quality. This data is then used to help delineate areas where ground-water quality degradation has occurred.

As funds allow, the entire Background Network will be re-sampled and all the parameters listed in Table 1 will be re-measured. This continued monitoring of the network will reveal water-quality changes over time, as well as targeting the onset of degradation or contamination.

A subset of the Background Network is the Temporal Variability Subnetwork (the "TV Net"). These wells are sampled more frequently (on a monthly or quarterly basis) for a smaller set of field parameters (Table 1). These field or "indicator parameters" will be used to quantify temporal water-quality variations. The feasibility of installing dedicated sampling equipment allowing continuous monitoring of a few selected wells is currently under consideration.

Refinement of the Background Network is an ongoing task. Wells which provide redundant information or do not represent baseline water quality are removed from the network. New wells are installed where needed.

VISA Network

The Very Intense Study Area (VISA) Network (Figure 3) monitors specific areas believed to be highly susceptible to ground-water contamination from surface sources. VISA Network wells are monitored for an extensive suite of chemical and field parameters, as well as organics, pesticides, herbicides and naturally-occurring radioactivity (Table 1). VISA's are selected based on an assessment of predominant land use and hydrogeologic susceptibility. The purpose of the VISA Network is to quantify the effects on ground-water chemistry of different land uses within a specific hydrogeologic environment. A VISA well is designed to monitor the effects of multiple sources of contamination on ground-water quality within a segment of the aquifer. Most VISA wells monitor the uppermost aquifer system present within the study area, since that is where surface-introduced contaminants should first be detected. This information might ultimately serve as a predictive tool, allowing ground-water professionals to ascertain the potential effects of changing land use on ground-water quality in areas with similar hydrogeological conditions.

Predominant land-use areas were located using the Florida Summary Mapping System, a microcomputer-mapping package developed at the University of Florida. The system contains land-use data derived from ad valorem tax information obtained from each of Florida's 67 counties. These data have been summarized for each square-mile section of the state based on the Public Land Survey System (section, Township and Range). This system allowed rapid access to a large volume of annually updated land-use data. One hundred Florida Department of Revenue land-use codes exist in the database; a subset of these were grouped into sixteen more general categories for the purpose of VISA selection.

Hydrogeologic conditions which determine aquifer-system vulnerability were determined using DRASTIC, a mapping system developed jointly by the U.S. Environmental Protection Agency and the National Water Well Association (Aller et al, 1985). DRASTIC is an acronym representing the seven hydrogeological parameters considered most indicative of relative pollution potential. These are:

D - Depth to water;

R - Net recharge;

A - Aquifer media;

S - Soil media;

T - Topography;

I - Impact of the vadose zone;

C - Hydraulic conductivity.

Each of these parameters is mapped separately for each aquifer, using existing data. Numerical scores are assigned to each map polygon. The score for each polygon is then multiplied by a weighting factor. The seven parameter maps are next overlain and the resulting polygons and weighted scores are summed to create a composite DRASTIC aquifer vulnerability map. Higher scores indicate higher relative pollution potential. These maps indicate overall relative aquifer-system vulnerability. Combined with the knowledge gained through analysis of the VISA Network results, these maps will be an invaluable land-use planning tool. DRASTIC maps are currently being produced for each county in Florida. These maps, covering the surficial and Floridan aquifer systems, will be published in a separate volume.

Twenty-one initial VISAs were selected, based on the above criteria (Table 2). Initial sampling of these VISAs occurred in late 1990. Results from these analyses will be published in a separate volume.

Private Well Survey

The Florida Department of Health and Rehabilitative Services (HRS) is conducting a survey of private drinking-water systems to determine their general water quality. DER and HRS entered into a cooperative agreement to select up to 70 wells per county (50 primary, 20 backup) for the survey, using the same criteria developed to select existing Background wells. HRS is sampling these wells for approximately 180 parameters (Table 1). The data generated from these wells is supplementing the Background and VISA data, while also indicating the general quality of water consumed by private well owners. The sampling process will not be completed for several years.

SAMPLING PROTOCOL

Sampling of the statewide network began in mid-1985 and was carried out by the water management districts. A portion of the existing wells were sampled using permanently installed pumps. The remaining existing wells and all new wells were sampled using teflon bailers, bladder pumps or submersible pumps specifically designed and manufactured with non-contaminating materials. Sampling protocol followed procedures established by the U.S. Environmental Protection Agency. All sampling agencies and analytical laboratories were required to submit quality assurance plans to maximize uniformity of results. The initial sampling episode included a more comprehensive set of physical and chemical parameters than were monitored

TABLE 1
GROUND WATER QUALITY NETWORK MONITORING PARAMETERS

PARAMETERS	NETWORK					STANDARD METHOD [1,2]
	Background	VISA	HRS	Quarterly	Monthly	
MAJOR IONS						
Bicarbonate	B	V		Q		406
Carbonate	B	V				406
Chloride	B	V	H	Q		407A, 407B, or 407D
Cyanide	B	V				412B, 412C, or 412D
Fluoride	B	V	H	Q		413A, 413B, 413C, or 413E
Nitrate	B	V	H	Q		418C or 418F
Phosphate	B	V	H	Q		424F or 424G
Sulfate				Q		426A or 426C
METALS						
Arsenic	B	V	H			303E
Barium	B	V	H			303C
Cadmium	B	V	H			303A or 303B
Calcium	B	V	H	Q		303A or 311C
Chromium	B	V	H			303A or 303B
Copper	B	V	H			303A
Iron	B	V	H	Q		303A or 315B
Lead	B	V	H			303A or 303B
Magnesium	B	V	H	Q		303A or 319B
Manganese	B	V	H	Q		303A or 319B
Mercury	B	V	H			303F
Nickel	B	V				303A or 322B
Potassium	B	V		Q		303A or 322B
Selenium	B	V	H			303E
Strontium		V				
Silver	B	V	H			303A or 303B
Sodium	B	V	H	Q		303A or 325B
Zinc	B	V	H	Q		303A or 303B
FIELD PARAMETERS						
Conductivity	B	V		Q	M	205
pH	B	V		Q	M	423
eH					M	
Dissolved Oxygen (DO)					M	
Temperature	B	V		Q	M	212
Water levels	B	V		Q	M	
Odor			H			
MICROBIOLOGICAL						
Fecal Coliform	B	V				908C or 909C
Total Coliform	B	V				908A or 909A
ORGANICS AND PESTICIDES						
Total Organic Carbon (TOC)	B	V		Q		505
Volatile Organic Carbon (VOC)	B					EPA 601 & 602, or EPA 624
Aldicarb & related compounds		V				EPA 531
Purgeable Halocarbons		V				EPA 601
Purgeable Aromatics		V	H			EPA 602
Pesticides		V				EPA Alt. 614
PCB's, Chlorinated Pesticides		V	H			EPA Alt. 617
Pesticides		V				EPA Alt. 619
Organophosphate Pesticides			H			EPA 622
Mixed Purgeables			H			EPA 624
Base / Neutral / Acid Extractables		V	H			EPA 625
Carbamate Pesticides		V	H			EPA 632
Pesticides		V				EPA 644
Herbicides			H			
Fumigant Pesticides		V	H			
RADIOMETRICS						
Gross Alpha	B	V				703
Gross Beta	B	V				703
Radon	B *					
Radium	B *					
OTHERS						
Total Dissolved Solids (TDS)	B	V		Q		209B
Ammonia		V				
Silica		V				

TABLE 2
LIST OF SELECTED VISAS BY WATER MANAGEMENT DISTRICT

LOCATION	AQUIFER	LAND USE	AREA (mi2)
ALACHUA COUNTY:			
1) Gainesville	Surficial	Mixed Urb./Suburb.	20
NORTHWEST FLORIDA WMD:			
1) Pensacola	Sand & Gravel	Heavy Industrial	~10
2) Gulf Breeze	Sand & Gravel	Mixed Urb./Suburb.	~10
3) SW Tallahassee	Surficial & Floridan	Light Industrial	~15
4) NE Jackson Co.	Unconfined Floridan	Cropland Agricul.	~120
5) Panama City	Surficial	Mixed Urban/Ind.	~25
ST. JOHNS RIVER WMD:			
1) Palm Bay	Surficial	Single Family	8
2) N. Lake Apopka	Surficial	Cropland Agricul.	39
3) Jax. Talleyrand	Surficial	Heavy Industrial	3
4) Ocala	Unconfined Floridan	Urban/Suburban	~3
SOUTH FLORIDA WMD:			
1) NE Dade Co.	Biscayne	Heavy Industrial	6
2) NE Broward Co.	Biscayne	Mixed Urban/Ind.	16
3) S. Orange Co.	Surficial	Mixed Urban/Ind.	28
4) Martin Co.	Surficial	Orchards, Citrus	30
5) S. Lee Co.	Surficial	Single-Family	6
SOUTHWEST FLORIDA WMD:			
1) E. Polk Co.	Surficial	Orchards, Citrus	20
2) E. Polk Co.	Floridan	Orchards, Citrus	20
3) NE Hillsborough	Surficial & Floridan	Single-Family	20
4) Pinellas Co.	Surficial	Light Industrial	7
SUWANNEE RIVER WMD:			
1) Live Oak	Unconfined Floridan	Mixed Urban/Ind.	~10
2) Lafayette Co.	Unconfined Floridan	Crop. Ag./Dairies	~30

NOTES, TABLE 1:

1 Methods are from Standard Methods for the Examination of Water and Wastewater, 15th edition (American Public Health Association, 1980), or from the Florida Department of Environmental Regulation's Supplement "A" to Standard Operating Procedures and Quality Assurance Manual (1981).

2 Other approved methods with the same or better minimum detection limits, accuracy and precision are also acceptable.

* A subset of approximately 100 Background Network wells is being sampled for radon and/or radium.

during subsequent routine sampling (Table 1).

The frequency of sampling and the chemical parameters monitored at each site were based on several factors, including network designation, land-use activity, available resources, and geologic sensitivity of the site. After initial sampling, several wells were dropped from one network and added to another, based on analysis of sampling results. For instance, some wells believed not to represent background-water quality were dropped from the Background Network and included in the VISA Network. This refinement process is ongoing. When significant concentrations of potentially harmful parameters were detected, the well was resampled to confirm or deny contamination. When contamination was confirmed in a private well, HRS was notified so that potential health threats could be assessed.

DATA BASE SYSTEMS

A variety of data base and software systems have been used and developed to store, manipulate and display information related to the Ground Water Quality Monitoring program. These include the Florida Summary Mapping System (FSMS), the Generalized Well Information System (GWIS), the Well Log Data System and DERMAP.

The FSMS is a microcomputer land-use database and retrieval system developed at the University of Florida (Miller, et al., 1986) and currently marketed by ARMASI, Inc. This system uses state ad valorem tax information annually compiled by each county tax assessor. Land-use information is compiled and displayed in raster format using the Public Land Survey System grid as a map base. The resulting one square mile resolution allows general delineation of areas of predominant land use.

GWIS is a microcomputer database and retrieval system which contains all well and analytical water-quality information generated by the network. It consists of two separate data sets: 1) physical well characteristics, and 2) sampling results. The two data sets are linked by a common well identifier. DER developed the system to quickly and efficiently manage the large volume of data generated by the network. Data can be retrieved by predefined groups or dates, for values exceeding specified limits (e.g. EPA standards), or by any combination of physical well attributes. Data entry programs allow the user to add new well and analytical information to the system. Output can be tabular or graphic (when combined with a PC CAD package). Network data is also available in dBASE III Plus format. GWIS programs and data are available to the public for a nominal disk charge or free via a computer bulletin board system, accessible by telephone. For further information, contact:

Florida Department of Environmental Regulation
Bureau of Drinking Water and Ground Water Resources
Ground Water Quality Monitoring Section
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Staff: (904) 488-3601
Bulletin Board Service: (904) 487-3592

The FGS maintains an extensive database of geologic well data (lithologic descriptions and formational contacts of well core and cutting samples). The Well Log Data System includes a series of BASIC programs written by Dr. Robert Lindquist (GeoLogic Information Systems, Gainesville, FL) to manage and use this database. The system was written for IBM-PC compatibility, providing the FGS and other users access to the statewide geologic database. It also provides a standard format for additions to the database. The programs can be used for data entry and editing, as well as for generating both graphic and text output of geologic data.

DERMAP integrates data from the FSMS, GWIS and the Well Log Data System. DERMAP was developed by ARMASI, Inc. in cooperation with GeoLogic Information Systems. DERMAP allows data from all three databases to be displayed simultaneously on a common map, allowing the user to visually relate water quality to land use and geology.

DERMAP and GWIS programs and data are available from DER. The FGS can be contacted for current well log data. FSMS can be obtained from ARMASI, Inc. and the Well Log Data System can be obtained from GeoLogic Information Systems. Appendix 1 contains contact information for these agencies and companies.

All network chemical and physical well information is also stored in DER's mainframe computer system. This central repository allows access to the data by other state agencies.

Data Analysis and Application of Program Results

The Ground Water Quality Monitoring Program was designed to improve understanding of man's impact on Florida's ground-water resources. Data collected and analyzed by this program will ultimately yield tools for describing and predicting the complex interactions between land use, hydrogeologic conditions, water quality and quantity. Specifically, data generated by the network will be analyzed to:

1. Determine the extent and thickness of the major aquifer systems containing potable water;
2. Define regional hydrogeological conditions;
3. Map recharge and discharge areas;
4. Map physical and chemical aquifer characteristics;
5. Statistically define geochemically-homogeneous segments within each aquifer system;
6. Determine the boundaries of ground-water basins and their relationship to the geochemically-defined aquifer segments;
7. Determine current general ground-water quality for each major aquifer system statewide;
8. Establish average baseline-and background-water quality by parameter and aquifer segment;
9. Determine effects of potential contamination sources;
10. Evaluate water-quality changes over time;
11. Define relationships between land use and ground-water quality;
12. Quantify and predict changes in ground-water quality due to land-use changes;
13. Delineate physical ground-water divides;
14. Correlation of ground-water quality changes with water-level fluctuations to aid in defining quality-quantity relationships;
15. Determine ground-water basins for each monitored aquifer;
16. Establish the baseline-water quality of similar aquifer sediments within each basin;
17. Produce water-quality maps by parameter.

Data generated by the Ground Water Quality Monitoring Program can be used to determine protective measures for water quality and quantity for a variety of practical applications. Example applications include:

1. Aiding land use planning and zoning decisions;
2. Development of Local Government Comprehensive Plans;
3. Protection of the quality and quantity of public water supplies;
4. Prediction of saltwater intrusion due to excessive fresh-water withdrawal in fields and coastal areas;
5. Surface-water/ground-water co-management;
6. Mapping of potential aquifer system vulnerability;
7. Development of aquifer resource management strategies and protection.

A GEOLOGICAL OVERVIEW OF FLORIDA

By

Thomas M. Scott, P.G. #99

Introduction

The State of Florida lies principally on the Florida Platform. The western panhandle of Florida occurs in the Gulf Coastal Plain to the northwest of the Florida Platform. This subdivision is recognized on the basis of sediment type and depositional history. The Florida Platform extends into the northeastern Gulf of Mexico from the southern edge of the North American continent. The platform extends nearly four hundred miles north to south and nearly four hundred miles in its broadest width west to east as measured between the three hundred foot isobaths. More than one-half of the Florida Platform lies under water leaving a narrow peninsula of land extending to the south from the North American mainland.

A thick sequence of primarily carbonate rocks capped by a thin, siliciclastic sediment-rich sequence forms the Florida Platform. These sediments range in age from mid-Mesozoic (200 million years ago [mya]) to Recent. Florida's aquifer systems developed in the Cenozoic sediments ranging from latest Paleocene (55 mya) to Late Pleistocene (<100,000 years ago) in age (Figure 4). The deposition of these sediments was strongly influenced by fluctuations of sea level and subsequent subaerial exposure. Carbonate sediment deposition dominated the Florida Platform until the end of the Oligocene Epoch (24 mya). The resulting Cenozoic carbonate sediment accumulation ranges from nearly two thousand feet thick in northern Florida to more than five thousand feet in the southern part of the state. These carbonate sediments form the Floridan aquifer system, one of the world's most prolific aquifer systems, regional intra-aquifer confining units and the sub-Floridan confining unit. The sediments supradjacent to the Floridan aquifer system include quartz sands, silts, and clays (siliciclastics) with varying admixtures of carbonates as discrete beds and sediment matrix. Deposition of these sediments occurred from the Miocene (24 mya) to the Recent. The Neogene (24 mya to 1.6 mya) and Quaternary (1.6 mya to the present) sediments form the intermediate aquifer system and/or confining unit and the surficial aquifer system (Figure 4).

Geologic History

Florida's basement rocks, those rocks older than Early Jurassic (>200 mya), are a fragment of the African Plate which remained attached to the North American Plate when the continents separated in the mid-Mesozoic. This fragment of the African Plate provided the base for the development of a carbonate platform which included the Bahama Platform and the Florida Platform (Smith, 1982). The Florida Straits separated the Bahama Platform from the Florida Platform by the beginning of the Late Cretaceous (approximately 100 mya) (Sheridan et al., 1981).

Carbonate sediments dominated the depositional environments from the mid-Mesozoic (approximately 145 mya) in southern and central Florida and from the earliest Cenozoic (approximately 62 mya) in northern and the eastern panhandle Florida. Carbonate sedimentation predominated in the Paleogene (67 to 24 mya) throughout most of Florida. Evaporite sediments, gypsum, anhydrite and some halite (salt), developed periodically due to the restriction of circulation in the carbonate depositional environments. The evaporites are most common in the Mesozoic and the Paleogene carbonates at and below the base of the Floridan aquifer system, where they help form the impermeable sub-Floridan confining unit.

During the early part of the Cenozoic, the Paleogene, the siliciclastic sediment supply from the north, the Appalachian Mountains, was limited. The mountains had eroded to a low level through millions of years of erosion. The minor amount of sediment reaching the marine environment was washed away from the Florida Platform by currents in the Gulf Trough (Suwannee Straits) (Figures 5a and b). This effectively protected the carbonate depositional environments of the platform from the influx of the siliciclastic sediments. As a result, the carbonates of the Paleogene section are very pure, with extremely limited quantities of siliciclastic sediments. In the central and western panhandle areas, which are part of the Gulf Coastal Plain, siliciclastic deposition continued well into the Paleogene. Significant carbonate deposition did not begin in this area until the Late Eocene (40 mya). During the later Eocene, as the influx of siliciclastics declined dramatically, carbonate depositional environments developed to the north and west of the limits of the Florida Platform. Carbonate deposition was continuous in the central panhandle and intermittent in the western panhandle through the Late Oligocene (approximately 28 mya).

During the Late Oligocene to Early Miocene, an episode of renewed uplift occurred in the Appalachians (Stuckey, 1965). With a renewed supply of sediments being eroded and entering the fluvial transport systems, siliciclastic sediments flooded the marine environment near the southeastern North American coastline. The influx of massive quantities of these sediments filled the Gulf Trough and encroached onto the carbonate platform through longshore transport, currents and other means. At first, the sands and clays were mixed with the carbonate sediments. Later, as more and more siliciclastics were transported south, the carbonate sediment deposition declined to only limited occurrences. Siliciclastic sediments, with varying amounts of carbonate in the matrix, dominated the depositional environments. The carbonate depositional environments were pushed further to the south until virtually the entire platform was covered with sands and clays. The influx of siliciclastics has diminished somewhat during the later Pleistocene and the Recent resulting in carbonate deposition occurring in limited areas around the southern portion of the Florida Platform.

The Miocene-aged siliciclastics appear to have completely covered the Florida Platform providing a relatively impermeable barrier to the vertical migration of ground water (Stringfield, 1966; Scott, 1981). This aquiclude protected the underlying carbonate sediments from dissolution. Erosion breached the confining unit by the early Pleistocene (?) allowing aggressive waters to dissolve the underlying carbonates. The progressive dissolution of the limestones enhanced the secondary porosity of the near-surface sediments of the Floridan aquifer system and allowed the development of numerous karst features.

Karst features formed in the Florida peninsula at least as early as the latest Oligocene as determined from the occurrence of terrestrial vertebrate faunas (MacFadden and Webb, 1982). Based on subsurface data from the interpretation of FGS cores, it appears that the development of karst in Florida occurred during the Paleogene. Unpublished work by Hammes and Budd (progress report to the FGS, U. Hammes and D. Budd, University of Colorado, 1990) indicates the occurrence of numerous "intraformational disconformities" which resulted in the development of "karst, caliche and other subaerial exposure features...". These disconformities were the result of sea level fluctuations on a very shallow water, carbonate bank depositional environment. At this time there is no documentation of large scale karst features forming during these episodes of exposure.

Structure

The oldest structures recognized as affecting the deposition of sediments of the Florida Platform are expressed on the pre-Middle Jurassic erosional surface (Arthur, 1988). These include the Peninsular Arch, South Florida Basin, Southeast Georgia Embayment, Suwannee Straits and the Southwest Georgia Embayment or Apalachicola Embayment (Figure 5a). These structures affected the deposition of the Mesozoic sediments and the Early Cenozoic (Paleogene) sediments. The structures recognized on the top of the Paleogene section are somewhat different than the older features. The younger features, which variously affected the deposition of the Neogene and Quaternary sediments, include the Ocala Platform, Sanford High, Chattahoochee Anticline, Apalachicola Embayment, Gulf Trough, Jacksonville Basin (part of the Southeast Georgia Embayment), Osceola Low and the Okeechobee Basin (Figure 5b). For more specific information on these structures and their origins refer to Chen (1965), Miller (1986) and Scott (1988a).

The occurrence and condition of the aquifer systems are directly related to their position with respect to the structural features. The Floridan aquifer system lies at or near the surface under poorly confined to unconfined conditions on the positive features such as the Ocala Platform, Sanford High and the Chattahoochee Anticline. Within the negative areas, (the Apalachicola Embayment, Jacksonville Basin, Osceola Basin and the Okeechobee Basin) the Floridan aquifer system is generally well confined. The intermediate aquifer system is generally absent

from the positive structures and best developed in the negative areas. The surficial aquifer system may occur anywhere in relation to these structures where the proper conditions exist.

The occurrence and development of the beds confining the Floridan aquifer system also relate to the subsurface structures. On some of the positive areas (Ocala Platform and Chattahoochee Anticline) the confining beds of the intermediate confining unit are absent due to erosion and possibly nondeposition. In those areas where the confining units are breached, dissolution of the carbonate sediments developed a karstic terrain. Dissolution of the limestones enhanced the porosity and permeability of the Floridan aquifer system including the development of some cavernous flow systems.

Geomorphology

Florida's land surface is relatively flat and has very low relief. The surface features of Florida are the result of the complex interaction of depositional and erosional processes. As sea level fluctuated during the later Cenozoic, the Florida Platform has repeatedly been inundated by marine waters resulting in marine depositional processes dominating the development of Florida's geomorphology. The relict shoreline features found throughout most of the state are most easily identified at lower elevations, nearer the present coastline. Inland and at higher elevations, these features have been subjected to more extensive erosion and subsequent modification by wind and water. In those areas of the state where carbonate rocks and shell-bearing sediments are subjected to dissolution, the geomorphic features may be modified by development of karst features. The extent of the modification ranges from minor sagging due to the slow dissolution of carbonate or shell to the development of large collapse sinkholes. The changes that result may make identification of the original features difficult.

White (1970) subdivided the State into three major geomorphic divisions, the northern or proximal zone, the central or mid-peninsular zone and the southern or distal zone (Figure 6). The northern zone encompasses the Northwest Florida Water Management District and the northern portions of the Suwannee River and St. Johns River Water Management Districts. The central zone includes the southern portions of the Suwannee River and St. Johns River Water Management Districts, the Southwest Florida Water Management District and the northern part of the South Florida Water Management District. The southern zone comprises the remainder of the South Florida Water Management District.

In a broad general sense, the geomorphology of Florida consists of the Northern Highlands, the Central Highlands and the Coastal Lowlands (White, Vernon and Puri in Puri and Vernon, 1964). White (1970) further subdivided these features as shown in Figures 7 thru 11. In general, the highlands are well drained while the lowlands often are swampy, poorly drained areas. The highland areas as delimited by White, Vernon and Puri in Puri and Vernon (1964) often coincide with the areas of "high recharge" as recognized by Stewart (1980). Only a few, limited areas of "high recharge" occur in the Coastal Lowlands.

Many of the highland areas in the peninsula to the central panhandle exhibit variably developed karst features. These range from shallow, broad sinkholes that develop slowly to those that are large and deep and develop rapidly (Sinclair and Stewart, 1985). The development of the karst features and basins has a direct impact on the recharge in the region. The karst features allow the rapid infiltration of surface water into the aquifer systems and offer direct access to the aquifers by pollutants.

Lithostratigraphy and Hydrostratigraphy

The aquifer systems in Florida are composed of sedimentary rock units of varying composition and induration which are subdivided into geologic formations based on the lithologic characteristics (rock composition and physical characteristics). Lithostratigraphy is the formal recognition of the defined geologic formations based on the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Many units are related by the similarities of the sediments while others may be defined on the sediment heterogeneity. An aquifer is a body of sediment or rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs (Bates and Jackson, 1987). Florida's primary aquifers are referred to as aquifer systems due to the complex nature of the water-producing zones they contain. The aquifer systems are identified independently from lithostratigraphic units and may include more than one formation or be limited to only a portion of a formation. The succession of hydrostratigraphic units forms the framework used to discuss the ground-water system in Florida (Figure 4) (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

The lithostratigraphic and hydrostratigraphic framework of Florida shows significant variability from north to south and west to east in the peninsula and the panhandle. The formational units discussed are only those Cenozoic sediments that relate to the Floridan aquifer system, the intermediate aquifer system/confining unit and the surficial aquifer system.

LITHOSTRATIGRAPHY

The lithostratigraphic units that comprise the aquifer systems in Florida occur primarily as subsurface units with very limited surface exposures. As a result of the generally low relief of the state, virtually all the lithostratigraphic descriptions are from well cuttings and cores used to study the sediments. Geophysical logs have proven useful in studying the sediments and attempting regional correlations (Chen, 1965; Miller, 1986; Scott, 1988a; Johnson, 1984).

The following description of the lithologic parameters of the various units associated with the aquifer systems is brief and generalized. More complete information concerning these groups and formations can be obtained by referring to Florida Geological Survey and U. S. Geological Survey publications relating to specific areas and/or specific aquifers. State-wide data concerning the thickness and tops of sediments of Paleocene (67-55 mya) and Eocene (55-38 mya) age (chronostratigraphic units) can be found in Chen (1965) and Miller (1986). Miller (1986) provides this data for Oligocene (38-25 mya) and Miocene (25-5.3 mya) sediments. Scott (1988a) provides detailed information on the Miocene strata in the eastern panhandle and peninsular areas. The Plio-Pleistocene (5.3-.01 mya) and the Holocene (.01 mya -Present) sediments which make up the surficial aquifer system, are discussed in a number of references which are cited in the appropriate section of this paper. Figure 4 shows the lithostratigraphic nomenclature utilized in this text.

Cenozoic Erathem
Tertiary System
Paleocene Series

In general, most of the Paleocene sediments in the Florida peninsula form the sub-Floridan confining unit and only a limited portion of these rocks are part of the Floridan aquifer system. Siliciclastic sediments predominate in the Paleocene section in much of the panhandle (Chen, 1965; Miller, 1986). The siliciclastic sediments are composed of low permeability marine clays, fine sands and impure limestone (Miller, 1986) which lie below the base of the Floridan aquifer system. Following Miller (1986), the siliciclastic sediments are referred to as "Undifferentiated Paleocene Rocks (Sediments)" and are not discussed further.

The siliciclastic sediments grade laterally into carbonate sediments across the Gulf Trough in the eastern panhandle (Chen, 1965). Carbonate sediments, mostly dolostone, occur interbedded with evaporite minerals throughout the Paleocene section in the peninsula (Chen, 1965). These sediments are included in the Cedar Keys Formation and occur throughout the peninsular area and into the eastern panhandle.

Cedar Keys Formation

The Cedar Keys Formation consists primarily of dolostone and evaporites (gypsum and anhydrite) with a minor percentage of limestone (Chen, 1965). The upper portion of the Cedar Keys consists of coarsely crystalline, porous dolostone. The lower portion of the Cedar Keys Formation contains more finely crystalline dolostone which is interbedded with anhydrite. The Cedar Keys Formation grades into the Undifferentiated Paleocene Sediments in the eastern panhandle (Miller, 1986) which equate with the Wilcox Group (Braunstein et al., 1988).

The configuration of the Paleocene sediments in peninsular Florida reflect depositional controls inherited from the pre-existing Mesozoic structures, including the Peninsular Arch, Southeast Georgia Embayment, and the South Florida Basin (Miller, 1986). The Cedar Keys Formation forms the base of the Floridan aquifer system throughout

the peninsula except in the northwestern-most peninsular area where the Oldsmar Formation forms the base (Miller, 1986). The upper, porous dolostone comprises the lowest beds of the Floridan aquifer system. The lower Cedar Keys Formation is significantly less porous, contains evaporites and forms the sub-Floridan confining unit.

Eocene Series

The sediments of the Eocene Series that form portions of the Floridan aquifer system are carbonates. During the Early Eocene, deposition followed a distribution pattern similar to the Paleocene carbonate sediments. However, through the Eocene, carbonate-forming environments slowly encroached further north and west over what had been siliciclastic depositional environments during the Paleocene. The Eocene carbonate sediments are placed in the Oldsmar Formation, Avon Park Formation and the Ocala Group. The Eocene carbonate sediments comprise a large part of the Floridan aquifer system.

Claiborne Group

The Lower to Middle Eocene Claiborne Group unconformably (?) overlies the undifferentiated Lower Eocene and Paleocene sediments. The Claiborne Group consists of the Tallahatta and Lisbon Formations which are lithologically nearly identical and are not separated. The group is composed of glauconitic, often clayey sand grading into fine-grained limestone to the south (Allen, 1987). The Claiborne Group ranges from 250 to 400 feet below NGVD and is up to 350 feet thick (Allen, 1987). It is unconformably overlain by the Ocala Limestone.

Oldsmar Formation

The Oldsmar Formation consists predominantly of limestone interbedded with vuggy dolostone. Dolomitization is usually more extensive in the lower portion of the section. Pore-filling gypsum and thin beds of anhydrite occur in some places, often forming the base of the Floridan aquifer system (Miller, 1986).

The Oldsmar Formation is recognized throughout the Florida peninsula. It grades laterally in the eastern panhandle into Undifferentiated Lower to Middle Eocene sediments equivalent to the Claiborne Group. The undifferentiated sediments are marine shales, siltstones, fine sandstones and impure limestones (Miller, 1986).

Avon Park Formation

The Middle Eocene sediments of peninsular Florida as originally described by Applin and Applin (1944) were subdivided, in ascending order, into the Lake City Limestone and the Avon Park Limestone. Miller (1986) recommended the inclusion of the Lake City in the Avon Park based on the very similar nature of the sediments. Miller also changed the term limestone to formation due to the presence of significant quantities of dolostone within the expanded Avon Park Formation.

The Avon Park Formation is primarily composed of fossiliferous limestone interbedded with vuggy dolostone. In a few, limited areas of west-central Florida, evaporites are present as vug fillings in dolostone.

The Avon Park Formation occurs throughout the Florida peninsula and the eastern panhandle in a pattern very similar to the underlying Oldsmar Formation. The oldest rocks cropping out in Florida belong to the Avon Park Formation. These sediments are locally exposed on the crest of the Ocala Platform in west-central peninsular Florida.

The carbonate sediments of the Avon Park Formation form part of the Floridan aquifer system and serve to subdivide it into an upper and lower Floridan in many areas. Miller (1986) recognized that portions of the Avon Park Formation are fine-grained and have low permeability, often acting as a confining bed in the middle of the Floridan aquifer system. In Brevard County, for example, these low permeability beds are relied upon to keep less desirable water injected into the lower Floridan from migrating into the potable water of the upper Floridan.

Ocala Limestone

Dall and Harris (1892) referred to the limestones exposed in central peninsular Florida near the city of Ocala in Marion County as the Ocala Limestone. Puri (1957) raised the Ocala to group and recognized formations based on the incorporated foraminiferal faunas. As a result of the biostratigraphic nature of these subdivisions, formational recognition is often difficult. In keeping with the intent of the Code of Stratigraphic Nomenclature, in this text, the Florida Geological Survey is returning to the use of the Ocala Limestone terminology.

The lower and upper subdivisions of the Ocala Limestone are based on distinct lithologic differences. The lower subdivision consists of a more granular limestone (grainstone to packstone). The lower facies is not present everywhere and may be partially to completely dolomitized in some regions (Miller, 1986). The upper unit is composed of variably muddy (carbonate), granular limestone (packstone to wackestone with very limited grainstone). Often this unit is very soft and friable with numerous large foraminifera. In southern Florida, virtually the entire Ocala Limestone consists of a muddy (carbonate) to finely pelletal limestone (Miller,1986). Chert is a common component of the upper portion of the Ocala Limestone. The Bumpnose "Formation", a very early Oligocene fossiliferous limestone, is lithologically very similar to the Ocala Limestone. It is included in the Ocala Limestone in this report.

The sediments of the Ocala Limestone form one of the most permeable zones within the Floridan aquifer system. The Ocala Limestone comprises much of the Floridan aquifer system in the central and western panhandle. The extensive development of secondary porosity by dissolution has greatly enhanced the permeability, especially in those areas where the confining beds are breached or absent. The Ocala Limestone forms the lower portion of the Floridan in the western panhandle (Wagner, 1982). In much of the peninsular area, it comprises all or part of the upper Floridan.

By Late Eocene, carbonate sediments were deposited significantly further to the north and west than had previously occurred during the Cenozoic. The Ocala Limestone is present throughout much of the State except where the unit has been erosionally removed. This occurs in outcrop on the crest of the Ocala Platform and in the subsurface on the Sanford High, a limited area in central Florida and a relatively large area in southernmost Florida (Miller, 1986). Chen (1965) suggests that the Ocala Limestone is also absent in a portion of Palm Beach County in eastern southern Florida. The surface and thickness of the Ocala Limestone are highly irregular due to dissolution of the limestones as karst topography developed.

Oligocene Series

The carbonate sediments of the Oligocene Series form much of the upper portion of the Floridan aquifer system in Florida. The depositional pattern of the Oligocene sediments shows that carbonate sediments were deposited well updip to the north of the Florida Platform (Miller, 1986). In the central panhandle and to the west, siliciclastic sediments began to be mixed with the carbonates.

The Oligocene sediments in peninsular Florida and part of the panhandle are characteristically assigned to the Suwannee Limestone. The Oligocene sediments in the central and western panhandle are placed in the Marianna, Bucatunna and Chickasawhay Formations (Miller, 1986). In the westernmost panhandle, the lower carbonates of the Suwannee Limestone grade into the siliciclastic Byram Formation (Braunstein et al., 1988).

Suwannee Limestone

The Suwannee Limestone consists primarily of variably vuggy and muddy (carbonate) limestone (grainstone to packstone). The occurrence of a vuggy, porous dolostone is recognized in the type area, the eastern to central panhandle and in southwest Florida. The dolostone often occurs interbedded between limestone beds.

The Suwannee Limestone is absent throughout a large area of the northern and central peninsula probably due to erosion. Scattered outliers of Suwannee Limestone are present within this area. Where it is present, the Suwannee Limestone forms much of the upper portion of the Floridan aquifer system. The reader is referred to Miller (1986) for a map of the occurrence of the Suwannee Limestone in the peninsula.

Marianna Limestone

The Marianna Limestone is a fossiliferous, variably argillaceous limestone (packstone to wackestone) that occurs in the central panhandle. It is laterally equivalent to the lower portion of the Suwannee Limestone. The Marianna Limestone forms a portion of the uppermost Floridan aquifer system in the central panhandle region.

Bucatunna Clay Member of the Byram Formation

The Bucatunna Clay Member is silty to finely sandy clay. Fossils are generally scarce in the Bucatunna (Marsh, 1966). The sand content of the Bucatunna ranges from very minor percentages to as much as 40 percent (Marsh, 1966).

The Bucatunna Clay Member has a limited distribution in the western panhandle. It occurs from the western end of the state eastward to approximately the Okaloosa-Walton County line where it pinches out (Marsh, 1966). The Bucatunna Clay Member provides an effective intra-aquifer confining unit in the middle of the Floridan aquifer system in the western panhandle.

Chickasawhay Formation

Marsh (1966) describes the Chickasawhay Formation as being composed of highly porous limestone and dolomitic limestone. This is often interbedded with porous to compact dolomitic limestone to dolostone. The Chickasawhay Formation grades into the upper Suwannee Limestone eastward. Due to difficulty in separating the Chickasawhay from the Lower Miocene limestones in the western panhandle, both Marsh (1966) and Miller (1986) included thin beds of possible Lower Miocene carbonate in the upper portion of the Chickasawhay Formation. The permeable sediments of the Chickasawhay Formation form part of the upper Floridan in the western panhandle (Wagner, 1982).

Miocene Series

The Miocene Epoch was a time of significant change in the depositional sequence on the Florida Platform and the adjacent Gulf and Atlantic Coastal Plains. During the early part of the Miocene, carbonate sediments continued to be deposited over most of the State. Intermixed with the carbonates were increasing percentages of siliciclastic sediments. By the end of the Early Miocene, the deposition of carbonate sediments was occurring only in southern peninsular Florida. Siliciclastic deposition dominated the Middle Miocene statewide with this trend continuing into the Late Miocene.

The basal Miocene carbonate sediments often form the uppermost portion of the Floridan aquifer system. The remainder of the Miocene sediments form much of the intermediate aquifer system and intermediate confining system. In some instances, these sediments may also be included in the surficial aquifer system.

Unusual depositional conditions existed during the Miocene as is evident from the occurrence of abundant phosphate, palygorskite, opaline cherts and other uncommon minerals plus an abundance of dolomite within the Hawthorn Group (Scott, 1988a). The presence of these minerals may influence ground-water quality in areas where the Miocene sediments are being weathered. Ground-water quality may also be affected where these sediments form the upper portion of the Floridan aquifer system or portions of the intermediate aquifer system.

Current geologic thought holds that in the peninsula the Miocene section is composed of the Hawthorn Group. The Tampa Formation is included as a member in the basal Hawthorn Group. In the panhandle, the Lower Miocene remains the Chattahoochee and St. Marks Formations, the Middle Miocene Alum Bluff Group and the Upper Miocene Choctawhatchee Formation and equivalents. Formations previously mentioned in the literature as being Miocene in age include the Tamiami, which is Pliocene in age, and the Miccosukee Formation which is now recognized as being Late Pliocene to possibly early Pleistocene in age.

The Miocene sediments are absent from the Ocala Platform and the Sanford High (Scott, 1988a). These sediments are as much as 800 feet thick in southwest Florida (Miller, 1986; Scott, 1988a), 500 feet thick in the northeastern peninsula (Scott, 1988a) and 900 to 1000 feet thick in the westernmost panhandle (Miller, 1986).

Chattahoochee Formation

The Chattahoochee Formation is predominantly a fine-grained, often fossiliferous, silty to sandy dolostone which is variable to a limestone (Huddlestun, 1988). Fine-grained sand and silt may also form beds with various admixtures of dolomite and clay minerals. Clay beds may also be common in some areas (Puri and Vernon, 1964).

The Chattahoochee Formation occurs in a limited area of the central panhandle from the axis of the Gulf Trough westward. It appears that the Chattahoochee grades to the west into a carbonate unit alternately referred to as Tampa Limestone (Marsh, 1966; Miller, 1986) or St. Marks (Puri and Vernon, 1964; NWFWMD Staff, 1975). Northward into Georgia, this unit grades into the basal Hawthorn Group (Huddlestun, 1988). To the east of the axis of the Gulf Trough, the Chattahoochee Formation grades into the St. Marks Formation (Puri and Vernon, 1964; Scott, 1986). The gradational change between the Chattahoochee and St. Marks Formations occurs over a broad area of Leon and Gadsden Counties (Scott, 1986). The sediments of the Chattahoochee Formation comprise the upper zone of the Floridan aquifer system in the central panhandle.

St. Marks Formation

The St. Marks Formation is a fossiliferous limestone (packstone to wackestone). Sand grains occur scattered in an often very moldic limestone. The lithology of the St. Marks and the associated units in the Apalachicola Embayment and to the west are often difficult to separate (Schmidt, 1984). The St. Marks Formation lithology can be traced in cores grading into the Chattahoochee Formation (Scott, 1986). This formation forms the upper part of the Floridan aquifer system in portions of the eastern and central panhandle.

Hawthorn Group

The Hawthorn Group is a complex series of the phosphate-bearing Miocene sediments in peninsular and eastern panhandle Florida. The carbonate sediments of the Hawthorn Group are primarily fine-grained and contain varying admixtures of clay, silt, sand and phosphate. Dolostone is the dominant carbonate sediment type in the northern two-thirds of the peninsula while limestone predominates in the southern peninsula and in the eastern panhandle area.

The siliciclastic sediment component consists of fine- to coarse-grained quartz sand, quartz silt and clay minerals in widely varying proportions. The clay minerals present include palygorskite, smectite and illite with kaolinite occurring in the weathered sediments.

The top of the Hawthorn Group is a highly irregular erosional and karstic surface. This unconformable surface can exhibit dramatic local relief especially in outcrop along the flanks of the Ocala Platform. Figures 12 through 19 show the top and thickness of the Hawthorn Group sediments which comprise the intermediate aquifer system/confining unit.

In the peninsula, the Hawthorn Group can be broken into a northern section and a southern section. The northern section consists of interbedded phosphatic carbonates and siliciclastics with a trend of increasing siliciclastics in the younger sediments. In ascending order, the formations in northern Florida are the Penney Farms, Marks Head and Coosawhatchee and its lateral equivalent Statenville (Scott, 1988a). The sediments comprising these formations characteristically have low permeabilities and form an effective aquiclude, the intermediate confining unit. In a few areas, permeabilities within the Hawthorn sediments are locally high enough to allow the limited development of an intermediate aquifer system.

The southern section consists of a lower dominantly phosphatic carbonate section and an upper phosphatic siliciclastic section. In the southern area, in addition to increasing siliciclastics upsection, there is also a trend of increasing siliciclastics from west to east in the lower carbonate section. The Hawthorn Group in southern Florida has been subdivided into, in

ascending order, the Arcadia Formation with the former Tampa Formation as a basal member, and the Peace River Formation (Scott, 1988a). Throughout much of south Florida, these sediments have limited or low permeabilities and form an effective intermediate confining unit. However, where the Tampa Member is present and permeable enough, it may form the upper portion of the Floridan aquifer system. In portions of southwestern Florida, the Hawthorn sediments are permeable enough to form several important producing zones in the intermediate aquifer system (Knapp et al., 1986; Smith and Adams, 1988).

The Hawthorn Group, Torreya Formation sediments in the eastern panhandle are predominantly siliciclastics with limited amounts of carbonates (Scott, 1988a). In this area, carbonates become increasingly important in the Gulf Trough where the basal Hawthorn sediments are fine-grained carbonates. The siliciclastic sediments are very clayey and form an effective intermediate confining unit. The carbonate sediments may locally be permeable enough to form the upper portion of the Floridan aquifer system.

Bruce Creek Limestone

Huddlestun (1976) applied the name Bruce Creek Limestone to late Middle Miocene limestones occurring in the Apalachicola Embayment and coastal areas of the central and western panhandle. The Bruce Creek Limestone is a fossiliferous, variably sandy limestone (Schmidt, 1984). This lithology becomes indistinguishable, to the east, from lithologies found in the St. Marks Formation (Schmidt, 1984). The Bruce Creek Limestone is laterally equivalent to and grades into the lower portion of the Alum Bluff Group (Schmidt, 1984). The Bruce Creek Limestone forms part of the upper Floridan aquifer system in the central and western panhandle.

Alum Bluff Group

West of the Apalachicola River in the Florida panhandle, the Hawthorn Group is replaced by the Alum Bluff Group. The Alum Bluff Group includes the Chipola Formation, Oak Grove Sand, Shoal River Formation and the Choctawhatchee Formation (Braunstein et al., 1988). The formations included in this group are generally defined on the basis of their molluskan faunas and are of variable areal extents. These sediments can be distinguished as a lithologic entity at the group level and will be referred to as such in this text.

The Alum Bluff Group consists of clays, sands and shell beds which may vary from a fossiliferous, sandy clay to a pure sand or clay and occasional carbonate beds or lenses. The Jackson Bluff Formation is currently thought to be Late Pliocene in age; and, even though Huddlestun (1976) included it in the Alum Bluff Group, it was not included in the Alum Bluff Group on the latest correlation charts (Braunstein et al., 1988). Sediments comprising the Jackson Bluff Formation are very similar to those making up the Alum Bluff Group.

The sediments comprising the Alum Bluff Group are generally impermeable due to the abundance of clay-sized particles. These sediments form an important part of the intermediate confining unit in the central panhandle.

Pensacola Clay

The Pensacola Clay consists of three members: lower and upper clay members and a middle sand member, the Escambia Sand (Marsh, 1966). Lithologically, the clay members consist of silty, sandy clays with carbonized plant remains (Marsh, 1966). The sand member is fine to coarse, quartz sand. Marine fossils are rarely present in the Pensacola Clay with the exception of a fossiliferous layer near the base (Clark and Schmidt, 1982). The Pensacola Clay grades laterally into the lower portion of the "Miocene Coarse Clastics" to the north and the Alum Bluff Group and the lower Intracoastal Formation to the east (Clark and Schmidt, 1982).

The Pensacola Clay forms the intermediate confining unit for the Floridan in the western panhandle. It lies immediately supradjacent to the limestones of the upper Floridan aquifer system.

Intracoastal Formation

Schmidt (1984) describes the Intracoastal Formation as a "very sandy, highly microfossiliferous, poorly consolidated, argillaceous, calcarenitic limestone." Phosphate is generally present in amounts greater than one percent. This unit is laterally gradational with the Pensacola Clay and Mio-Pliocene "Coarse Clastics" (Schmidt, 1984). The lower Intracoastal Formation is Middle Miocene while the upper portion is Late Pliocene. Wagner (1982) indicates that the Intracoastal Formation forms part of the intermediate confining unit in the central to western panhandle.

Pliocene-Pleistocene Series

The sediments of the Pliocene-Pleistocene Series occur over most of the State. These sediments range from nonfossiliferous, clean sands to very fossiliferous, sandy clays and carbonates. Lithologic units comprising this series include the "Coarse Clastics", Tamiami Formation, Citronelle Formation, Miccosukee Formation, Cypresshead Formation, Nashua Formation, Caloosahatchee Formation, Fort Thompson Formation, Key Largo Limestone, Miami Limestone, Anastasia Formation and Undifferentiated Pleistocene-Holocene sediments. The upper portion of the Intracoastal Formation is Pliocene and is discussed with the lower Intracoastal Formation under the Miocene Series.

"Coarse Clastics"

The name "Coarse Clastics" has been applied to sequences of quartz sands and gravels in a number of areas around Florida. These sediments are often referred to in the literature as "Miocene Coarse Clastics" (for example, Puri and Vernon, 1964).

In northern Florida, these sediments are referred to as the Cypresshead Formation of Late Pliocene to Early Pleistocene age (Scott, 1988b). In southern Florida, Knapp et al. (1986) referred to these sediments as the "Miocene Coarse Clastics" and placed them in the Hawthorn Group. In the panhandle, Marsh (1966) mentions the "Miocene Coarse Clastics" as sands and gravel with some clay which underlie the Citronelle Formation.

In the panhandle, the "Coarse Clastics" are variably clayey sands with gravel and some shell material (Clark and Schmidt, 1982). These siliciclastics occur in Escambia, Santa Rosa and western Okaloosa Counties in the western panhandle. They equate in part to the upper part of the Pensacola Clay, part of the Intracoastal Formation and part of the Alum Bluff Group.

In southern peninsular Florida, the coarse siliciclastics are fine to very coarse quartz sands with quartz gravel and variable amounts of clay, carbonate and phosphate. These sediments may equate with the Cypresshead Formation sediments in central and northern Florida.

These siliciclastic sediments form important aquifer systems in portions of southern and panhandle Florida. In the western panhandle, the "Coarse Clastics" form a portion of the Sand-and-Gravel aquifer, part of the surficial aquifer system. These sediments also comprise a portion of the surficial aquifer system in the peninsular area, especially in southern Florida.

Tamiami Formation

The Tamiami Formation consists of the Pinecrest Sand Member, the Ochopee Limestone Member, and the Buckingham Limestone Member (Hunter, 1968). The various facies of the Tamiami occur over a wide area of southern Florida. The relationships of the facies are not well known due to: 1- the complex set of depositional environments that were involved in the formation of the sediments and 2- the Tamiami Formation most often occurs as a shallow subsurface unit throughout much of its extent. Many of the facies are important from a hydrogeologic perspective in an area of ground-water problems.

The limestone in the Tamiami Formation occurs as two types: 1- a moderately to well-indurated, slightly phosphatic, variably sandy, fossiliferous limestone (Ochopee) and 2- a poorly indurated to unindurated, slightly phosphatic, variably sandy, fossiliferous limestone (Buckingham). The sand facies is often composed of a variably phosphatic and sandy, fossiliferous, calcareous, quartz sand often containing abundant, well-preserved mollusk shells (Pinecrest). The sand varies from a well-sorted, clean sand with abundant well-preserved shells and traces of silt-sized phosphate in the type Pinecrest Sand Member (Hunter, 1968) to a clayey sand with sand-sized phosphate, clay-sized carbonate in the matrix and abundant, well preserved mollusk shells. Siliciclastic sediments (undifferentiated) of this age appear to occur along the eastern side of the peninsula but have not been assigned to the Tamiami Formation.

Sediments of the Tamiami Formation exhibit

variable permeabilities and form the lower Tamiami aquifer and Tamiami confining beds of the surficial aquifer system (Knapp et al., 1986). Smith and Adams (1988) indicate that the upper Tamiami sediments form the basal portion of the "water table aquifer" overlying the Tamiami confining beds.

Citronelle Formation

The Citronelle Formation is composed of fine to very coarse siliciclastics. The name was extended to include the siliciclastics comprising the *central ridge system* in the Florida peninsula by Cooke (1945). As it is currently recognized, the Citronelle Formation occurs only in the panhandle. The unit is recognized from central Gadsden County on the east to the western boundary of the State. The Citronelle Formation is composed of very fine to very coarse, poorly sorted, angular to subangular quartz sand. The unit contains significant amounts of clay, silt and gravel which may occur as beds, lenses or stringers and may vary rapidly over short distances. Limonite nodules and limonitic cemented zones are common.

The Citronelle Formation extends over much of the central and western panhandle. Previous investigators encountered problems in the separation of the Citronelle and the overlying terrace deposits and generally considered the thickness of the Citronelle including these younger sediments (Marsh, 1966; Coe, 1979). The Citronelle Formation grades laterally into the Miccosukee Formation through a broad transition zone in Gadsden County. The Citronelle Formation forms an important part of the Sand-and-Gravel aquifer in the western panhandle and produces up to 2,000 gallons of water per minute (Wagner, 1982).

Miccosukee Formation

Hendry and Yon (1967) describe the Miccosukee Formation as consisting of interbedded and cross-bedded clay, silt, sand and gravel of varying coarseness and admixtures. Limonite pebbles are common in the unit. The Miccosukee Formation occurs in the eastern panhandle from central Gadsden County on the west to eastern Madison County on the east. Due to its clayey nature, the Miccosukee Formation does not produce significant amounts of water. It is generally considered to be part of the surficial aquifer system (Southeastern Geological Society, 1986).

Cypresshead Formation

The name Cypresshead Formation was first used by Huddlestun (1988). It was extended into Florida by Scott (1988b). The Cypresshead Formation is composed entirely of siliciclastics; predominantly quartz and clay minerals. The unit is characteristically a mottled, fine- to coarse-grained, often gravelly, variably clayey quartz sand. As a result of weathering, the clay component of these sediments has characteristically been altered to kaolinite. Clay serves as a binding matrix for the sands and gravels. Clay content may vary from absent to more than fifty percent in sandy clay lithologies although the average clay content is 10 to 20 percent. These sediments are often thinly bedded with zones of cross bedding. The Cypresshead Formation appears to occur in the Central Highlands of the peninsula south to northern Highlands County, although the extent of the Cypresshead Formation has not been accurately mapped in this area. This unit may locally comprise the surficial aquifer system where clay content is low.

Nashua Formation

The Nashua is a fossiliferous, variably calcareous, sometimes clayey, quartz sand. The fossil content is variable from a shelly sand to a shell hash. The dominant fossils are mollusks.

The extent of the Nashua in northern Florida is not currently known. It extends some distance into Georgia and appears to grade laterally into the Cypresshead Formation (Huddlestun, 1988). The Nashua Formation may produce limited amounts of water in localized areas where it forms part of the surficial aquifer system.

Caloosahatchee Formation

The Caloosahatchee Formation consists of fossiliferous quartz sand with variable amounts of carbonate matrix interbedded with variably sandy, shelly limestones. The sediments vary from non-indurated to well indurated. The fauna associated with these sediments are varied and often well preserved. Fresh water limestones are commonly present within this unit.

Sediments identified as part of the Caloosahatchee Formation by various investigators occur from north of Tampa on the west coast south to Lee County, eastward to the East Coast then northward into northern Florida (DuBar, 1974). The Caloosahatchee Formation as used here includes those sediments informally referred to as the Bermont formation (DuBar, 1974).

In most hydrogeologic investigations of southern Florida, the Caloosahatchee Formation is not differentiated from the Fort Thompson Formation and other faunal units. The undifferentiated sediments form much of the surficial aquifer system.

Fort Thompson Formation

The Fort Thompson Formation consists of interbedded shell beds and limestones. The shell beds are characteristically variably sandy and slightly indurated to unindurated. The sandy limestones present in the Fort Thompson Formation were deposited under both freshwater and marine conditions. The sand present in these sediments is fine- to medium-grained. The sediments of Fort Thompson age in central Florida along the east coast, consist of fine to medium quartz sand with abundant mollusk shells and a minor but variable clay content.

The Fort Thompson Formation, as the Caloosahatchee Formation, is part of the undifferentiated sediments in southern Florida. It forms a portion of the surficial aquifer system.

Key Largo Limestone

The Key Largo Limestone is a coralline limestone composed of coral heads encased in a matrix of calcarenite (Stanley, 1966). Hoffmeister and Multer (1968) indicate that the Key Largo Limestone occurs in the subsurface from as far north as Miami Beach to as far south as the Lower Keys. The fossil reef tract represented by the Key Largo sediments may be as much as 8 miles wide (DuBar, 1974). Near the northern and southern limits of the Key Largo Limestone, it is overlain conformably by the Miami Limestone with which the Key Largo is, in part, laterally equivalent.

The Key Largo Limestone forms a part of the Biscayne aquifer of the surficial aquifer system. The Biscayne aquifer provides water for areas of Dade, Broward and Monroe Counties.

Miami Limestone

The Miami Limestone includes an oolitic facies and a bryozoan facies. The bryozoan facies underlies and extends west of the western boundary of the oolitic facies. The bryozoan facies consists of calcareous bryozoan colonies imbedded in a matrix of ooids, pellets and skeletal sand. It generally occurs as a variably sandy, recrystallized, fossiliferous limestone (Hoffmeister et al., 1967). The oolitic facies consists of variably sandy limestone composed primarily of oolites with scattered concentrations of fossils.

Hoffmeister et al. (1967) indicate that the Miami Limestone covers Dade County, much of Monroe County and the southern part of Broward County. It grades laterally to the south into the Key Largo Limestone and to the north into the Anastasia Formation. The oolitic facies underlies the Atlantic Coastal Ridge southward from southern Palm Beach County to southern Dade County.

The Miami Limestone forms a portion of the Biscayne aquifer of the surficial aquifer system. It is very porous and permeable due to the dissolution of carbonate by ground water as it recharges the aquifer system.

Anastasia Formation

The Anastasia Formation consists of interbedded quartz sands and coquinoid limestones. The sand beds consist of fine to medium-grained, variably fossiliferous, calcareous, quartz sand. The contained fossils are primarily broken and abraided mollusk shells. The limestone beds, commonly called coquina, are composed of shell fragments, scattered whole shells and quartz sand enclosed in a calcareous matrix, usually sparry calcite cement.

The Anastasia Formation forms the Atlantic Coastal Ridge through most of its length (White, 1970). Natural exposures of this unit occur scattered along the east coast from St. Augustine south to southern Palm Beach County near Boca Raton. South of this area the Anastasia Formation

grades into the Miami Limestone. Cooke (1945) felt that the Anastasia Formation extended no more than three miles inland from the Intracoastal Waterway. Field work by this author (Scott) suggests that the Anastasia may extend as much as 10 miles inland; although, Schroeder (1954) suggests that this unit may occur more than 20 miles inland.

The Anastasia Formation forms a portion of the surficial aquifer system along the eastern coast of the state. Ground water is withdrawn from the Anastasia Formation in many areas along the Atlantic Coastal Ridge where, locally, it may be the major source of ground water. Near the southern extent of the Anastasia Formation, it forms a portion of the Biscayne aquifer (Hoffmeister, 1974).

Undifferentiated Pleistocene-Holocene Sediments

The sediments referred to as the "undifferentiated Pleistocene-Holocene sediments" cover much of Florida effectively hiding most older sediments. Included in this category are marine "terrace" sediments, eolian sand dunes, fluvial deposits, fresh water carbonates, peats and a wide variety of sediment mixtures. These sediments often occur as thin layers overlying older formations and are not definable as formations. As such, these sediments have been referred to by many different names including Pliocene to Recent sands, Pleistocene sands, Pleistocene Terrace Deposits.

The sediments incorporated in this category are most often quartz sands. The sands range from fine- to coarse-grained, nonindurated to poorly indurated and nonclayey to slightly clayey. Gravel may be present in these sediments in the panhandle area. Other sediments included in this group include peat deposits, some clay beds, and freshwater carbonates. The freshwater carbonates occur in many freshwater springs and in large areas of the Everglades.

Locally, these sediments may form a portion of the surficial aquifer system. The greatest thicknesses of these sediments occurs infilling paleokarst features where more than 300 feet of undifferentiated Pleistocene-Holocene sediments have been recorded (Florida Geological Survey, unpublished well data).

HYDROSTRATIGRAPHY

The hydrostratigraphy of the Florida Platform has been the focus of numerous investigations by the various water management districts, the USGS and the FGS. The hydrostratigraphic framework recognized in Florida consists of a thick sequence of Cenozoic sediments which comprise the Floridan aquifer system, the intermediate aquifer system/confining unit and the surficial aquifer system (Figure 4) (Southeastern Geological Society Ad Hoc Committee, 1986). The Floridan aquifer system underlies much of the State, providing abundant potable water for a rapidly expanding population (Figure 20). In limited areas throughout the State, the intermediate aquifer system is utilized. Water is also withdrawn from the surficial aquifer system in many areas particularly in the western panhandle and southern Florida. As an example, Figure 21 illustrates the extent and occurrence of ground-water systems in the NWFWMD area of the panhandle.

The hydrologic parameters of each aquifer system vary widely from one area of the state to another as do the lithologies of the sediments. Hydrologic subdivisions do not have to conform to the lithostratigraphic framework.

Each water management district has identified surface-water basins and ground-water areas. The surface-water basins (Figures 22 through 26) delineate the areas influenced by the tributaries of the major drainage features. The ground-water areas (Figures 27 through 31) were delineated as convenient study areas. Maps representing the potentiometric surface of the Floridan aquifer system were constructed for each district (Figures 32 through 36).

Surficial aquifer system

The surficial aquifer system is defined by the Southeastern Geological Society (SEGS) Ad Hoc Committee on Florida Hydro-stratigraphic Unit Definition (1986) as "the permeable hydrologic unit contiguous with the land surface that is comprised principally of unconsolidated to poorly indurated, siliciclastic deposits. It also includes well-indurated carbonate rocks, other than those of the Floridan aquifer system where the Floridan is at or near land surface. Rocks making up the surficial aquifer system belong to all or part of the Upper Miocene to Holocene Series. It contains the water table, and the water within it is under mainly unconfined conditions; but beds of low permeability may cause semi-confined or locally confined conditions to prevail in its deeper parts. The lower limit of the surficial aquifer system coincides with the top of the laterally extensive and vertically persistent beds of much lower permeability".

Some areas of the state rely heavily upon the surficial aquifer system for potable water in areas where the water quality of the Floridan aquifer system is poor. The two main aquifers of the surficial aquifer system to which names have been applied are the Sand and Gravel Aquifer of northwestern panhandle Florida and the Biscayne Aquifer in southeastern Florida. The distribution of these aquifers is limited (Figure 20). Maps delineating the thickness of the surficial aquifer system were provided by the Northwest Florida Water Management District (NWFWMD) (Figure 37) and Southwest Florida Water Management District (SWFWMD) (Figure 38). The South Florida Water Management District provided a map of the base of the surficial aquifer system (Figure 39). Figure 40 depicts those areas of the SJRWMD where the surficial aquifer system is a primary ground-water supplier.

The surficial aquifer system is composed of Pliocene to Holocene quartz sands, shell beds and carbonates (Figure 4). In the Florida panhandle, these units include the Citronelle and Miccosukee Formations and undifferentiated sediments. In the northern portion of the peninsula, sediments belonging to the Anastasia Formation, Cypresshead Formation and Undifferentiated Sediments, which include shell beds and limestones that are time equivalent to the Caloosahatchee and Fort Thompson Formations, comprise the surficial aquifer system. In southern Florida, the surficial aquifer system consists of the Tamiami, Caloosahatchee, Fort Thompson, and Anastasia Formations, the Key Largo and Miami Limestones and the undifferentiated sediments. Following the definition of the Tamiami as proposed by Hunter and Wise (1980), the portion of the Tamiami previously considered to be the lower Tamiami confining unit now forms the upper part of the Hawthorn Group of the intermediate confining unit. Where a clay bed separates the upper and lower limestones of the Tamiami, as in Hendry County (Smith and Adams, 1988), the clay bed is recognized as a thin confining unit within the surficial aquifer system.

Intermediate aquifer system/confining unit

The SEGS (1986) defines the intermediate aquifer system/ confining unit as "all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. These rocks in general consist of fine-grained siliciclastic deposits interlayered with carbonate strata belonging to all or parts of the Miocene and younger series. In places, poorly-yielding to non-water-yielding strata mainly occur and there the term "intermediate confining unit" applies. In other places, one or more low- to moderate-yielding aquifers may be interlayered with relatively impermeable confining beds; there the term "intermediate aquifer system" applies. The aquifers within this system contain water under confined conditions.

The top of the intermediate aquifer system/confining unit "coincides with the base of the surficial aquifer system. The base of the intermediate aquifer [or confining unit] is at the top of the vertically persistent, permeable, carbonate section that comprises the Floridan aquifer system, or, in other words, that place in the section where siliciclastic layers of significant thickness are absent and permeable carbonate rocks are dominant. Where the upper layers of the persistent carbonate section are of low permeability, they are part of either the intermediate aquifer system or intermediate confining unit, as applicable to the area."

The sediments comprising the intermediate aquifer system/confining unit exhibit wide variability over the state. In the central and western panhandle, this section acts principally as an intermediate confining unit for the Floridan aquifer system. The formations belonging to the intermediate confining unit include the Alum Bluff Group, Pensacola Clay, Intracoastal Formation, and the Chipola Formation (SEGS, 1986). In the eastern panhandle, the confining unit includes primarily the

Hawthorn Group sediments. Figures 41 and 42 show the top and thickness of the intermediate confining unit in the NWFWMD area while Figures 12 and 13 show the top and thickness of the Hawthorn Group sediments in the eastern part of the District. In the northern peninsula, the Hawthorn Group sediments form the intermediate confining unit with minor occurrences of aquifer zones (Figures 14 through 17). In the southern peninsula, the Hawthorn Group sediments form both an intermediate confining unit and an intermediate aquifer system. The top and thickness of the intermediate aquifer system/confining unit in the SWFWMD area is shown in Figures 43 and 44. The top and isopach of the Hawthorn Group sediments in southern Florida (SWFWMD and SFWMD) are shown on Figures 18 and 19. In many areas of the state, impermeable carbonates of Eocene and Oligocene age may form the base of the intermediate confining unit. Conversely, permeable carbonates occurring at the base of the Hawthorn Group may be hydraulically connected to the Floridan aquifer system and locally form the top of the Floridan.

The intermediate aquifer system plays a very important role in the ground-water resources of southwestern peninsular Florida. In the Lee County and surrounding areas, the intermediate aquifer system provides relatively large quantities of potable water. The Hawthorn Group may contain two producing zones (Wedderburn et al., 1982) referred to as the mid-Hawthorn aquifer and the sandstone aquifer. Figure 45 illustrates the top of the mid-Hawthorn confining zone in Lee County. Figure 46 delineates the base of the sandstone aquifer while Figure 47 shows the top of the mid-Hawthorn aquifer.

The intermediate confining unit occurs widespread in the state providing an effective aquiclude for the Floridan aquifer system. On the crests of the Ocala Platform, Sanford High, St. Johns Platform, Brevard Platform and the Chattahoochee Anticline (Figure 4) these beds are absent due to erosion. In these areas, surface water has a direct avenue to recharge the Floridan aquifer system. Immediately surrounding these areas, the intermediate confining unit is present but is breached by karst features which also allow surface water and water from the surficial and intermediate aquifer systems direct access to the Floridan. In the west-central portion of the peninsula and along the west coast from Hillsborough County into the eastern panhandle, the intermediate confining unit is generally absent and the Floridan aquifer system occurs unconfined. In the east-central peninsula, the intermediate confining unit is thin and provides only limited confinement for the underlying Floridan aquifer system. Miller (1986) mapped a maximum thickness of the intermediate confining unit as being greater than 1000 feet thick in the western-most panhandle and in southwestern Florida.

Floridan aquifer system

The Floridan aquifer system is one of the world's most productive aquifers. The sediments that comprise the aquifer system underlie the entire state although potable water is not present everywhere (Figure 20).

The Floridan aquifer system may occur as a continuous series of vertically connected carbonate sediments or may be separated by sub-regional to regional confining beds (Miller, 1986). Often the confining beds consist of low permeability carbonates. In the western panhandle, the intra-aquifer confining unit is the Bucatunna Clay. Elsewhere, the confining beds are carbonate sediments belonging to the Ocala Limestone, Avon Park Formation or the Oldsmar Formation. When intra-aquifer confining beds are present, the Floridan aquifer system can be subdivided into an upper and lower Floridan. Figures 48 through 51 indicate the configuration of the top and the thickness of the upper and lower limestones of the Floridan aquifer system. Figures 52 and 53 reveal the top and thickness of the Bucatunna Clay, the intra-aquifer confining unit in the western panhandle. Figure 54 shows the top of the lower Floridan aquifer system in the SJRWMD area.

The Floridan aquifer system in peninsular Florida and the eastern panhandle is composed of all or parts of the Cedar Keys Formation, Oldsmar Formation, Avon Park Formation, Ocala Limestone, Suwannee Limestone, St. Marks Formation and, possibly, the basal carbonates of the Hawthorn Group in limited areas of the state (Figure 4). The Floridan aquifer system encompasses the Ocala Limestone, Marianna Limestone, Suwannee Limestone, Chickasawhay Limestone, Chattahoochee Formation, St. Marks Formation and Bruce Creek Limestone (Figure 4) in the central and western panhandle.

The elevation of the upper surface of the Floridan aquifer system is directly related to the positioning on the major structural features (Figure 5). The top of the Floridan aquifer system ranges in elevation from greater than +100 feet NGVD on the Ocala Platform and Chattahoochee Arch to more than -1400 feet NGVD in the western-most panhandle and more than -1100 feet NGVD in the Okeechobee Basin of southern Florida (Figures 55 through 59). The thickness of the Floridan aquifer system (including those areas where water from the Floridan aquifer system may not be potable) varies from less than 100 feet along the state line in north-central panhandle to more than 3000 feet in the Apalachicola Embayment and 3400 feet in southern peninsular Florida (Figures 60 through 64). The base of the Floridan aquifer system in the NWFWMD area is shown in Figure 65.

The degree of confinement of the Floridan aquifer system also varies in relation to the position of the major structural features. The Floridan may be unconfined or semiconfined on the major features including the Ocala Platform and the Chattahoochee Anticline (Figures 66 through 68). In the negative areas such as the Jacksonville Basin, Okeechobee Basin and the Gulf Coast Basin, the Floridan aquifer system is well confined. Many areas of central peninsular Florida and in the eastern panhandle exhibit the development of karst features that breach the confining unit allowing localized recharge to occur. Figure 69 illustrates the NWFWMD area karst development. Throughout most of southern Florida, particularly the SFWMD area, the Floridan aquifer system occurs under confined conditions. The thickness of the beds confining the Floridan aquifer system in the SWFWMD area is shown in Figure 70.

Recharge to the Floridan aquifer system is directly related to the confinement of the system. The highest recharge rates occur where the Floridan is unconfined or poorly confined as in those areas where the Floridan aquifer system is at or near land surface (Figure 71). Recharge may also be high in areas where the confining layers are breached by karst features as shown for the NWFWMD area (Figure 69). Figures 72 through 76 indicate the relative recharge rates around the state.

The potentiometric surface of the Floridan aquifer system varies widely throughout the state. In localized areas, the potentiometric surface may be affected by intensive pumpage of ground water. Figures 32 through 36 indicate the elevation of this surface relative to NGVD. In those areas where the potentiometric surface is higher than the ground elevation, artesian conditions occur. Figures 77 through 82 delineate the areas where artesian flow is expected based on current data.

The intrusion of saline waters into fresh water producing zones is a major concern for Florida's coastal, and some inland, communities. Excessive pumpage of fresh water may draw the saline waters laterally or may cause an upconing of underlying nonpotable water. The salt water that can affect the potable water supply may be connate water trapped during the deposition of the sediments forming the aquifer system. It may represent saline waters that entered the aquifer system during previous high sea level stands which have not been flushed from the aquifer. The limits of salt water intrusion are shown on Figures 83 through 86.

The Claiborne aquifer occurs in a limited area of the central-northern panhandle. It is a permeable portion of the sub-Floridan Confining Unit in that area. It is poorly defined and rarely used at this time (Allen, 1987).

CONCLUSION

This volume presents a review of the current knowledge of the Cenozoic lithostratigraphy and hydrostratigraphy as it relates to ground water in Florida. This publication represents the efforts of the five water management districts, the Department of Environmental Regulation and the Florida Geological Survey, Department of Natural Resources to provide a geologic framework of the state's ground-water resources. Recognition of the geologic framework of the aquifer systems and confining units is imperative for determining and understanding the ambient ground-water quality in Florida. Through recognizing the geologic framework, areas that are particularly sensitive to pollution may be defined and proper ground-water management techniques can be applied to protect these resources.

REFERENCES

Allen, T. W., 1987, Hydrogeology of the Holmes, Jackson and Washington Counties area, Florida: unpublished MS Thesis, Florida State University, Tallahassee, FL 183 p.

Aller, L., Bennett, T., Lehr, J. H., and Petty, R. J., 1985, DRASTIC: a standardized system for evaluating ground water pollution potential using hydrogeologic settings: United States Environmental Protection Agency - 600/2-85/018, 163 p.

Applin, P. L., and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and southern Georgia: American Association of Petroleum Geologists Bulletin, v. 28, pp. 1673-1753.

American Public Health Association, 1980, Standard methods for the examination of water and wastewater, 15th edition: American Public Health Association, Washington, D.C.

Arthur, J. D., 1988, Petrogenesis of Early Mesozoic tholeiite in the Florida basement and overview of Florida basement geology: Florida Geological Survey Report of Investigation 97, 39 p.

Barr, G. L., 1989, Potentiometric surface of the upper Floridan Aquifer, West-central Florida, May 1989, United States Geological Survey Open File Report 89-393.

Bates, R. L., and Jackson, J. A., (eds.) 1987, Glossary of Geology: American Geological Institute, 788 p., Alexandria, Virginia.

Braunstein, J., Huddlestun, P., and Biel, R., 1988, Gulf Coast region correlation of stratigraphic units of North America: American Association of Petroleum Geologists, Correlation Chart.

Buono, A., Speckler, R. M., Barr, G. L., and Wolansky, R. M., 1979, Generalized thickness of the confining bed overlying the Floridan Aquifer, Southwest Florida Water Management District: United States Geological Survey Open File Report 79-1171.

Causseaux, K. W., and Fretwell, J. D., 1982, Position of the saltwater-freshwater interface in the upper part of the Floridan Aquifer, Southwest Florida: United States Geological Survey Open File Report 82-90.

Chen, C. S., 1965, The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geological Survey Bulletin 45, 105 p.

Clark, M. W., and Schmidt, W., 1982, Shallow stratigraphy of Okaloosa County and vicinity, Florida: Florida Geological Survey Report of Investigations 92, 28 p., 19 fig.

Coe, C. J., 1979, Geology of the Plio-Pleistocene sediments in Escambia and Santa Rosa Counties, Florida: Masters Thesis, Florida State University Department of Geology, Tallahassee, Florida, 115 p.

Cooke, C. W., 1945, Geology of Florida: Florida Geological Survey Bulletin 29, 339 p.

Corral, M. A., Jr., and Wolansky, R. M., 1984, Generalized thickness and configuration of the top of the intermediate aquifer, west-central Florida: United States Geological Survey Open File Report 84-4018.

Dall, W. H., and Harris, G. D., 1892, Correlation papers-Neocene: U.S. Geological Survey Bulletin 84, 349 p.

DuBar, J. R., 1974, Summary of the Neogene stratigraphy of Southern Florida: from Post Miocene stratigraphy of the Central and Southern Atlantic Coastal Plain, 1974, Utah State University Press, Logan, Utah, 206 p.

Fernald, E. A., and Patton, D. J., 1984, Water resources atlas of Florida: Florida State University Institute of Science and Public Affairs, 291 p.

Florida, State of, 1983, Florida Statutes, Section 403 - Water quality assurance act, Chapter 17-4.2455 - Ground water quality monitoring: 1983 Florida Legislature, Tallahassee, Florida.

Florida Department of Environmental Regulation, 1981, Supplement "A" to standard operating procedures and quality assurance manual: Florida Department of Environmental Regulation, Solid Waste Section, Tallahassee, Florida, 110 p.

Hendry, C. W., Jr., and Yon, J. W., Jr., 1967, Stratigraphy of Upper Miocene Miccosukee Formation, Jefferson and Leon Counties, Florida: American Association of Petroleum Geologists Bulletin, v. 51, pp. 250-256.

Hoffmeister, J. E., 1974, Land from the sea: University of Miami Press, Coral Gables, FL, 143 p.

______________, Stockman, K. W., and Multer, H. G., 1967, Miami Limestone of Florida and its Recent Bahamiam counterpart: Geological Society of America Bulletin 78.

______________, and Multer, H. G., 1968, Geology and origin of the Florida Keys: Geological Society of America Bulletin 79, pp. 1487-1502.

Huddlestun, P. F., 1976, The Neogene stratigraphy of the Central Florida Panhandle: Unpublished Dissertation, Florida State University Department of Geology, Tallahassee, Florida.

______________, 1988, A revision of the lithostratigraphic units of the Coastal Plain of Georgia: Georgia Geological Survey Bulletin 104, 162 p.

Hunter, M. E., 1968, What is the Caloosahatchee Marl?: In Hydrogeology of South-central Florida: Southeastern Geological Society 22nd Annual Field Trip Guidebook, pp. 61-88.

______________, and Wise, S. W., 1980, Possible restriction and redefinition of the Tamiami Formation of South Florida: Points of Discussion (Abs.): Florida Scientist, v. 43, supplement 1, 42 p.

Knapp, M. S., Burns, W. S., and Sharp, T. S., 1986, Preliminary assessment of the groundwater resources of western Collier County, Florida: In South Florida Water Management District Technical Publication #86-1, Part 2 - Appendices.

Johnson, R. A., 1984, Stratigraphic analysis of geophysical logs from water wells in peninsular Florida: St. Johns River Water Management District Technical Publication SJ84-16, 76 p.

MacFadden, B. J., and Webb, S. D., 1982, The succession of Miocene (Arikareean through Hemphillian) terrestrial mammalian localities and faunas in Florida: in Scott, T. M., and Upchurch, S. B. (eds.), Miocene of the Southeastern United States, proceedings of the symposium, Florida Geological Survey Special Publication 25, pp. 186-199.

Marsh, O. T., 1966, Geology of Escambia and Santa Rosa Counties, Western Florida Panhandle: Florida Geological Survey Bulletin 46, 140 p.

Miller, J. A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

Miller, W. L., Alexander, J. F., Frazier, D. L., and Hatchitt, J. L., 1986, An information system to locate potential threats to groundwater resources: University of Florida, Gainesville, Florida, 160 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, pp. 841-875.

Northwest Florida Water Management District, 1975, Staff report - Water Resources Assessment, 126 p.

Puri, H. S., 1957, Stratigraphy and zonation of the Ocala Group: Florida Geological Survey Bulletin 38, 248 p.

__________, and Vernon, R. O., 1964, Summary of the geology of Florida: Florida Geological Survey Special Publication 5 (Revised), 312 p.

Schmidt, W., 1984, Neogene stratigraphy and geologic history of the Apalachicola Embayment, Florida: Florida Geological Survey Bulletin 58, 146 p.

Schroeder, M. C., 1954, Stratigraphy of the outcropping formations in southern Florida: Southeastern Geological Society, 8th Field Trip Guidebook, pp. 18-48.

Scott, T. M., 1981, The Paleoextent of the Miocene Hawthorn Formation in peninsular Florida (abs.): Florida Scientist, v. 44, Supplement 1, p. 42.

__________, 1986, The lithostratigraphic relationships of the Chattahoochee, St. Marks and Torreya formations, eastern Florida Panhandle: Florida Academy of Sciences, Abstract, Florida Scientist v. 49, supplement 1.

__________, 1988a, The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida: Florida Geological Survey Bulletin 59, 148 p.

__________, 1988b, The Cypresshead Formation in Northern Peninsular Florida: in Pirkle, F. L., and Reynolds, J. G., (eds.) Southeastern Geological Society Annual Field Trip Guidebook, February 19-20, 1988, pp. 70-72.

Sheridan, R. E., Crosby, J. T., Bryan, G. M., and Stoffa, P. L., 1981, Stratigraphy and structure of Southern Blake Plateau, Northern Florida Straits and Northern Bahama Platform from multichannel seismic reflection data: American Association of Petroleum Geologists Bulletin 65, n. 12, pp. 2571-2593.

Sinclair, W. C., and Stewart, J. W., 1985, Sinkhole type development and distribution in Florida: Prepared by the U.S. Geological Survey, Florida Geological Survey Map Series 110, Scale: 50 km to 1 inch.

Smith, D. M., 1982, Review of the tectonic history of the Florida basement: Tectonophysics, v. 88, pp. 1-22.

Smith, K. R., and Adams, K. M., 1988, Ground water resource assessment of Hendry County, Florida: in South Florida Water Management District Technical Publication 88-12, Part II - Appendices.

Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986, Hydrogeological units of Florida: Florida Geological Survey Special Publication 28, 8 p.

Stanley, S. M., 1966, Paleoecology and diagenesis of Key Largo Limestone, Florida: American Association of Petroleum Geologists Bulletin, v. 50, pp. 1927-1947.

Stewart, J. W., 1980, Areas of natural recharge to the Floridan aquifer in Florida. Prepared by the U.S. Geological Survey in cooperation with the Florida Department of Environmental Regulation/Florida Geological Survey Map Series 98, Scale: 30 miles to 1 inch.

Stringfield, V. T., 1966, Artesian water in Tertiary limestone in the Southeastern States: U. S. Geological Survey Professional Paper 517, 226 p.

Stuckey, J. L., 1965, North Carolina: Its geology and mineral resources: North Carolina Department of Conservation and Development, 550 p.

U. S. Environmental Protection Agency, 1980, Standard operating procedures and quality assurance manual: United States Environmental Protection Agency, Region IV, Athens, Georgia, 203 p.

U. S. Environmental Protection Agency, 1982, Handbook for sampling and sample preservation of water and wastewater: United States Environmental Protection Agency, Cincinnati, Ohio, 402 p.

Wagner, J. R., 1982, Hydrogeology of the Northwest Florida Water Management District: in Fisher, G. (ed.) Ground Water in Florida, proceedings of the First Annual Symposium on Florida Hydrogeology, Northwest Florida Water Management District, Public Information Bulletin 82-2, pp. 37-50.

Wagner, J. R., 1989, Potentiometric surface of the Floridan aquifer system in the Northwest Florida Water Management District, May, 1986: Northwest Florida Water Management District Water Resources Map Series 89-001.

Wedderburn, L. A., Knapp, M. S., Waltz, D. P., and Burns, W. S., 1982, Hydrogeologic reconnaissance of Lee County, Florida: South Florida Water Management District Technical Publication 82-1, 192 p.

White, W. A., 1970, Geomorphology of the Florida Florida Panhandle: Florida Geological Survey Bulletin 51, 164 p.

Wolansky, R. M., and Garbode, J. M., 1981, Generalized thickness of the Floridan Aquifer, Southwest Florida Water Management District: United States Geological Survey Open File Report 80-1288.

__________, Speckler, R. K., and Buono, A., 1981, Generalized thickness of the surficial deposits above the confining bed overlying the Floridan Aquifer, Southwest Florida Water Management District: United States Geological Survey Open File Report 79-1071.

APPENDIX 1

Additional Sources of Information

ALACHUA COUNTY DEPARTMENT OF ENVIRONMENTAL SERVICES
#1 Southwest 2nd Place
Gainesville, Florida 32606
(904) 336-2442

DADE COUNTY DEPARTMENT OF ENVIRONMENTAL RESOURCE MANAGEMENT
111 Northwest 1st Street
Suite 1310
Miami, Florida 33128
(305) 375-3318

FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION
Bureau of Drinking Water and Ground Water Resources
Ground Water Quality Monitoring Section
2600 Blair Stone Road
Tallahassee, Florida 32399
(904) 488-3601

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT
Route 1, Box 3100
Havana, Florida 32333
(904) 539-5999

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
P.O. Box 1429
Palatka, Florida 32078
(904) 328-8321

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
P.O. Box 24680
3301 Gun Club Road
West Palm Beach, Florida 33416
(407) 694-0546

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
Tampa Service Office
7601 U.S. 301 North
Tampa, Florida 33637
(813) 985-7481

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
Route 3, Box 64
Live Oak, Florida 32060
(904) 362-1001

Database and Software Distributors

FLORIDA SUMMARY MAPPING SYSTEM (FSMS) - Land Use Database:

Automated Resource Mapping & Analysis Systems Integration
(ARMASI, Inc.)
P.O. Box 13027
Gainesville, Florida 32607
(904) 462-2955

WELL LOG DATA SYSTEM (WLDS) - Well Log Analysis Software:

GeoLogic Information Systems
P.O. Box 15224
Gainesville, Florida 32604
(904) 338-1128

Well Log Data can be obtained from:

FLORIDA GEOLOGICAL SURVEY
903 West Tennessee Street
Tallahassee, Florida 32304-7700
(904) 488-9380

GENERALIZED WELL INFORMATION SYSTEM (GWIS), DERMAP (Integral Mapping Package for GWIS, WLDS, FSMS), Ground Water Quality Data (GWIS or dBASE III+ format):

Florida Department of Environmental Regulation
Bureau of Drinking Water and Ground Water Resources
Ground Water Quality Monitoring Section
2600 Blair Stone Road
Tallahassee, Florida 32399-2400
(904) 488-3601

Computer Bulletin Board System (904) 487-3592

* The BBS (Computer Bulletin Board) allows access to GWIS and the most recent water quality data from any PC with a modem, telephone line and communications software. The BBS runs 24 hours a day, seven days a week. Users can either run GWIS remotely, performing retrievals and then downloading the results, or can download the full program and data sets for use on another PC.

DERMAP and GWIS are also available on disk by mail, for a small media fee. Contact the DER staff for further information.

APPENDIX 2

List of Related Reports and Publications

ALACHUA COUNTY:

Regan, J., R. Hallbourg and T. Newman
1987 Design and Implementation of an Ambient Ground Water Quality Network in Alachua County (unpublished report): Alachua County Department of Environmental Services (DER Contract WM134).

Trifilio, J. and R. Hallbourg
1989 The Ground Water Quality Monitoring Program in Alachua County, FL, 1988 to 1989, Volume 1: Alachua County Department of Environmental Services (DER Contract WM206).

(Geologic Information Systems, Inc. staff)
1989 The Ground Water Quality Monitoring Program in Alachua County, FL, 1988 to 1989, *Volume 2 - Well Log Data Summary*: Alachua County Department of Environmental Services (DER Contract WM206).

Trifilio, J. and R. Chambers
1989 The Ground Water Quality Monitoring Program in Alachua County, FL, 1988 to 1989, *Volume 3 - Background Network field data sheets*: Alachua County Department of Environmental Services (DER Contract WM206).

DADE COUNTY:

Baker, J.A.
1987 *Survey of Chlorinated Pesticide Residues in* Ground Water in Rural Areas of Dade County: Dade County Department of Environmental Resource Management Technical Report 88-5; 66 p. (DER Contract WM98).

APPENDIX 2
(Continued)

DEPARTMENT OF ENVIRONMENTAL REGULATION:

Humphreys, C.L.
1985 Florida Ground Water Monitoring Plan (pamphlet): 8 p.

Glover, N.T.
1985 A Generalized Well Information Inventory System: Proceedings, Practical Applications of Ground Water Models, Columbus, Ohio; p. 1-4.

______ 1986 A Large Scale Data Base Management System for the Manipulation of Monitor Well Analytical Results: Southeastern Ground Water Symposium Proceedings; Orlando, Florida; p. 167-170.

Humphreys, C.L., G.L. Maddox, R.E. Copeland, and N.T. Glover
1986 Organization and Implementation of Florida's Statewide Ambient Ground Water Quality Monitoring Network: Southeastern Ground Water Symposium Proceedings; Orlando, Florida; p. 3-19.

Glover, N.T and G.L. Maddox
1987 A Comparator Value for Targeting Monitor Networks (abstract): Southeastern Ground Water Symposium Proceedings; Orlando, Florida; p. 3.

______ 1988 Ground Water (Florida State of the Environment brochure series); 20 p.

Maddox, G.L. and J. Spicola
1990 Ground Water Quality Monitoring Network (Florida State of the Environment brochure series); 20 p.

FLORIDA STATE UNIVERSITY:

Cooper, W.T.
1986 Effects of Well Casing Materials on the Integrity of Ground Water Samples Taken for Chemical Analysis: unpublished draft, FSU Department of Chemistry; 77 p. (DER Contract WM116).

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT:

Wagner, J.R., T.W. Allen, L.A. Clemens and J.B. Dalton
1984 Ambient Ground Water Monitoring Program, Phase 1: unpublished report, NWFWMD (DER Contract WM65).

Bartel, R.L and J.D. Barksdale
1985 Hydrogeologic Assessments of Solid Waste Landfills in Northwest Florida: NWFWMD Water Resources Special Report 85-1; 104 p. (DER Contract WM101).

Wilkins, K.T., J.R. Wagner and T.W. Allen
1985 Hydrogeologic Data for the Sand and Gravel Aquifer in Southern Escambia County, Florida: NWFWMD Technical File Report 85-2; 53 p. (DER Contract WM71).

Bartel, Ronald L
1986 Hydrogeology and Contaminant Movement at Selected Solid Waste Landfills in Northwest Florida: NWFWMD Water Resources Special Report 86-2; 119 p. (DER Contract WM101).

Clemens, L.A., J.B. Dalton and R.D. Fendick
1987 Ambient Ground Water Quality in Northwest Florida, Part 1: Ground Water Sampling and Analysis, Ambient Ground Water Monitoring Program: NWFWMD Water Resources Special Report 87-1, 103 p. (DER Contract WM115).

Clemens, L.A.
1988 Ambient Ground Water Quality in Northwest Florida, Part 2: A Case Study in Regional Ground Water Monitoring - Wakulla Springs, Wakulla County, Florida: NWFWMD Water Resources Special Report 88-1, 25 p. (DER Contract WM115).

SOUTH FLORIDA WATER MANAGEMENT DISTRICT:

Anderson, S.O.
1986 South Dade Agricultural Pilot Study: SFWMD Technical Memorandum (DER Contract WM69).

Herr, J.
1986 Okeechobee County Airport Landfill Investigation Pilot Study: SFWMD Technical Memorandum; 87 p. (DER Contract WM69).

Whalen, P.J. and M.G. Cullum
1988 An Assessment of Urban Land Use/Stormwater Runoff Quality Relationships and Treatment Efficiencies of Selected Stormwater Management Systems: SFWMD Technical Publication 88; 52 p. (DER Contract WM142).

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT:

Moore, D.L., D.W. Martin, S.T. Walker and J.T. Rauch
1986 Design and Establishment of a Background Ground-Water Quality Monitor Network in the Southwest Florida Water Management District: SWFWMD, Brooksville, FL; 141 p. (DER Contract WM77).

Moore, D.L., D.W. Martin, S.T. Walker, J.T Rauch and G. Jones
1986 Initial Sampling Results of a Background Ground-Water Quality Monitor Network in the Southwest Florida Water Management District: SWFWMD, Brooksville, FL; 393 p. (DER Contract WM77).

(SWFWMD Staff)
1988 Lithologic Descriptions from Wells Drilled by the Ambient Ground-Water Quality Monitoring Program (Second Revision): SWFWMD, Brooksville, FL; 93 p. (DER Contract WM137).

UNIVERSITY OF FLORIDA:

Alexander, J., W. Miller, J. Hatchitt, D. Frazier and D.Costakis
1986 An Information System to Locate Potential Threats to Groundwater Resources: unpublished report, University of Florida; 160 p. (DER Contract SP103).

Miller, W.L. and M. Brusseau
1987 Method for Producing Improved Estimates of Pesticide Use: unpublished report, University of Florida; 32 p. (DER Contract WM140).

Miller, W.L., R. Bass and C. Lin
1987 An Investigation of Solid Waste Landfills in the South Florida Water Management District: University of Florida (DER Contract WM142).

Hornsby, A.G., K.D. Pennell, R.E. Jessup and P.S.C. Rao
1988 Modeling Environmental Fate of Toxic Organic Chemicals in Soils: University of Florida Institute of Food and Agricultural Sciences; 72 p. (DER Contract WM149).

Hatchitt, J.L.
1990 The Florida Summary Mapping System - A Land Use Analysis Package (User Manual): ARMASI, Inc.; 79 p. (DER Contract WM207).

U. S. GEOLOGICAL SURVEY:

1985 Results of a Water Quality Reconaissance of Selected Springs (unpublished report): USGS (DER Contract WM88).

Seaber, P.R. and M.E. Thagard
1986 Identification and Description of Potential Ground Water Quality Monitoring Wells in Florida: USGS Water Resources Investigations Report 85-4130, 124 p.

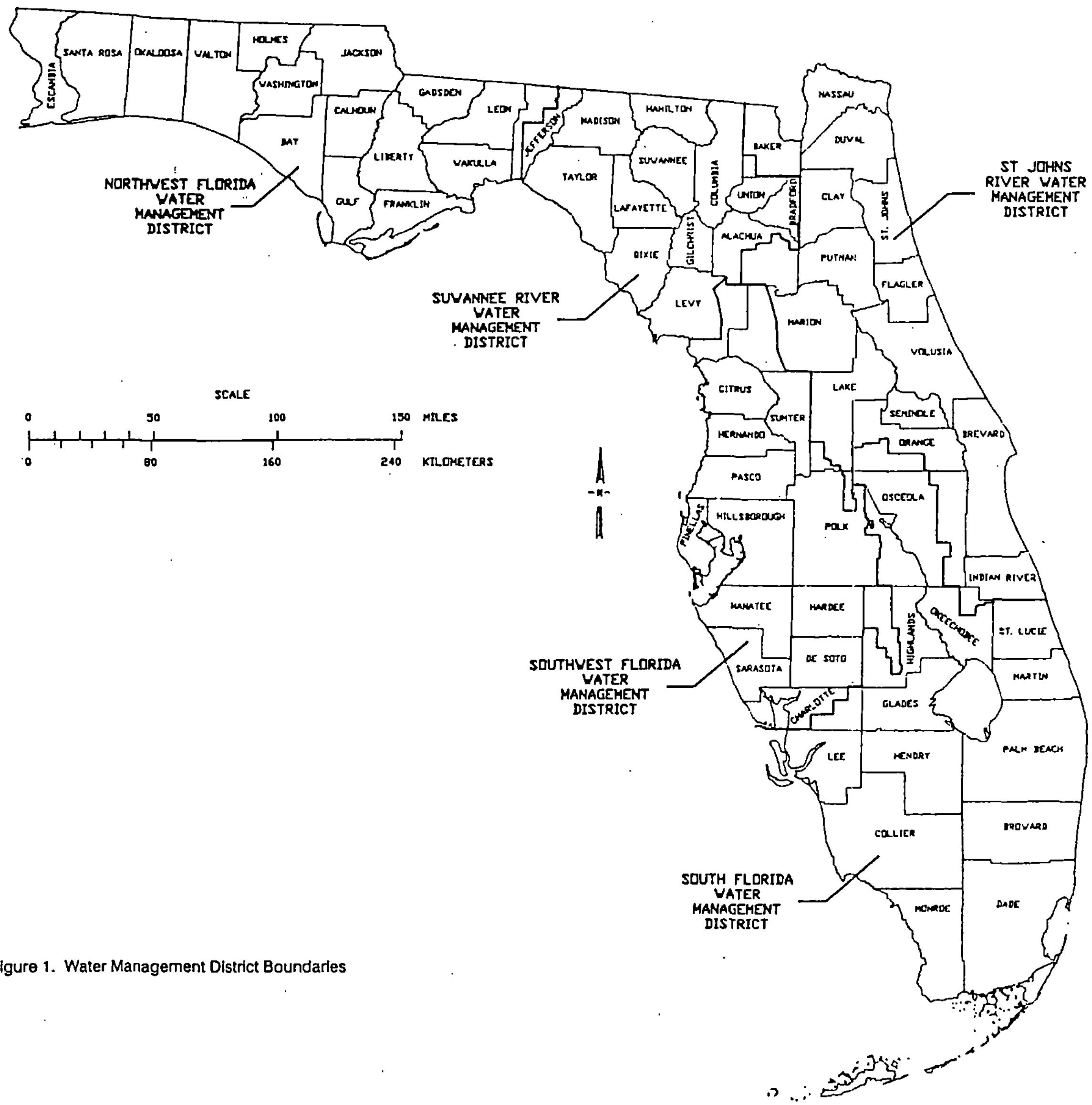


Figure 1. Water Management District Boundaries

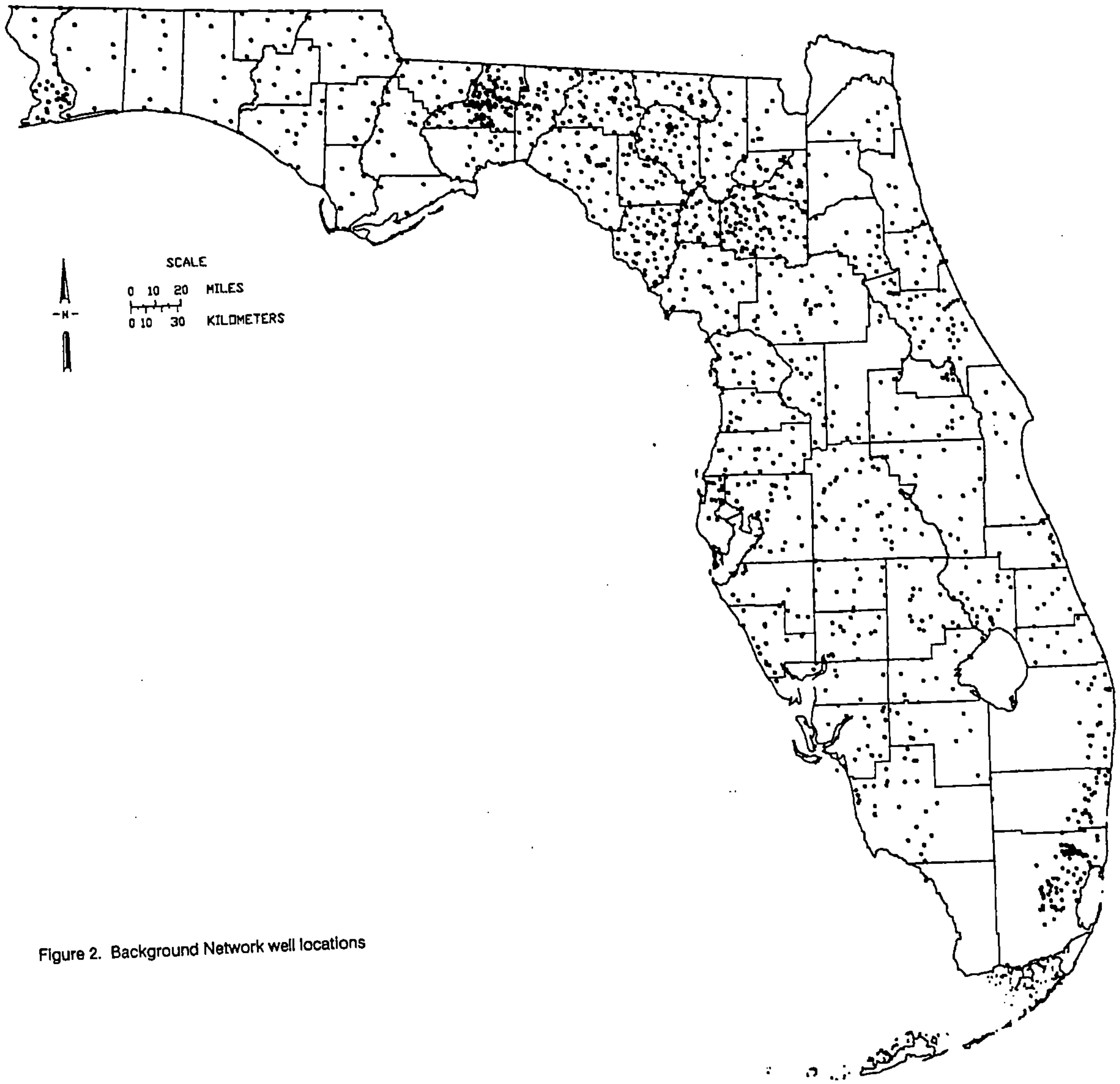


Figure 2. Background Network well locations

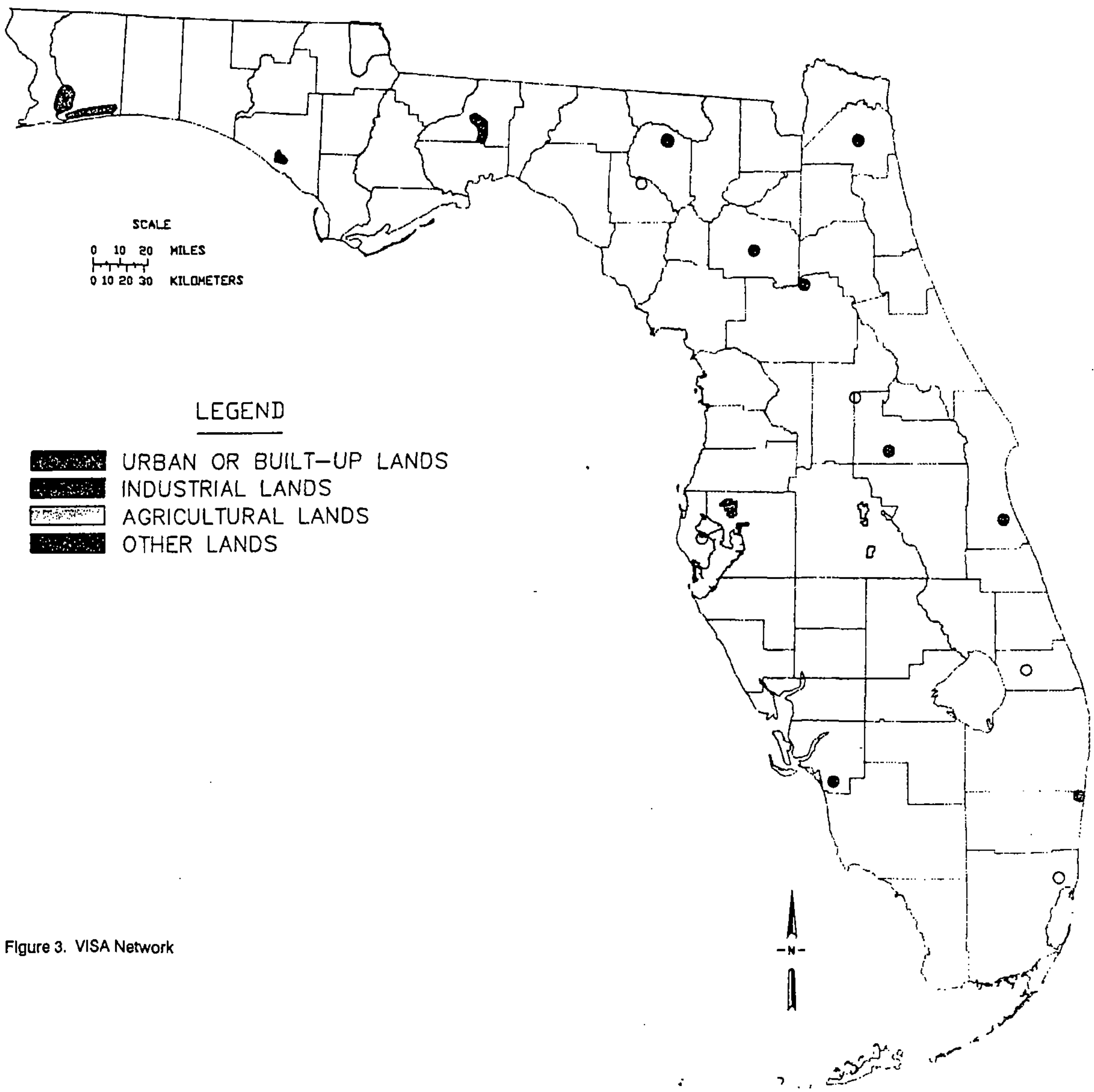


Figure 3. VISA Network

		PANHANDLE FLORIDA		NORTH FLORIDA		SOUTH FLORIDA	
SYSTEM	SERIES	LITHOSTATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT	LITHOSTRATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT	LITHOSTATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT
QUATERNARY	HOLOCENE	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM
	PLEISTOCENE			MICCOSUKEE FORMATION		MIAMI LIMESTONE KEY LARGO LIMESTONE ANASTASIA FORMATION FORT THOMPSON FORMATION CALOOSAHATCHEE FM.	
TERTIARY	PLIOCENE	CITRONELLE FORMATION MICCOSUKEE FORMATION COARSE CLASTICS		CYPRESSHEAD FORMATION NASHUA FORMATION		TAMIAMI FORMATION	
	MIOCENE	ALUM BLUFF GROUP PENSACOLA CLAY INTRACOASTAL FORMATION HAWTHORN GROUP BRUCE CREEK LIMESTONE ST.MARKS FORMATION CHATTAHOOCHEE FORMATION	INTERMEDIATE CONFINING UNIT	HAWTHORN GROUP STATENVILLE FORMATION COOSAWHATCHIE FM. MARKSHEAD FORMATION PENNEY FARMS FORMATION ST. MARKS FORMATION	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT	HAWTHORN GROUP PEACE RIVER FORMATION BONE VALLEY MEMBER ARCADIA FORMATION TAMPA-NOCATEE MEMBERS	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT
	OLIGOCENE	CHICKASAWHAY LIMESTONE SUWANNEE LIMESTONE MARIANNA LIMESTONE BUCATUNNA CLAY	FLORIDAN AQUIFER SYSTEM	SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM	SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM
	EOCENE	OCALA LIMESTONE CLAIBORNE GROUP UNDIFFERENTIATED SEDIMENTS	SUB-FLORIDAN CONFINING UNIT	OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION		OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION	
	PALEOCENE	UNDIFFERENTIATED PALEOCENE ROCKS		CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT	CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT
CRETACEOUS AND OLDER		UNDIFFERENTIATED		UNDIFFERENTIATED		UNDIFFERENTIATED	

Figure 4. Hydrostratigraphic Nomenclature (modified from Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986)

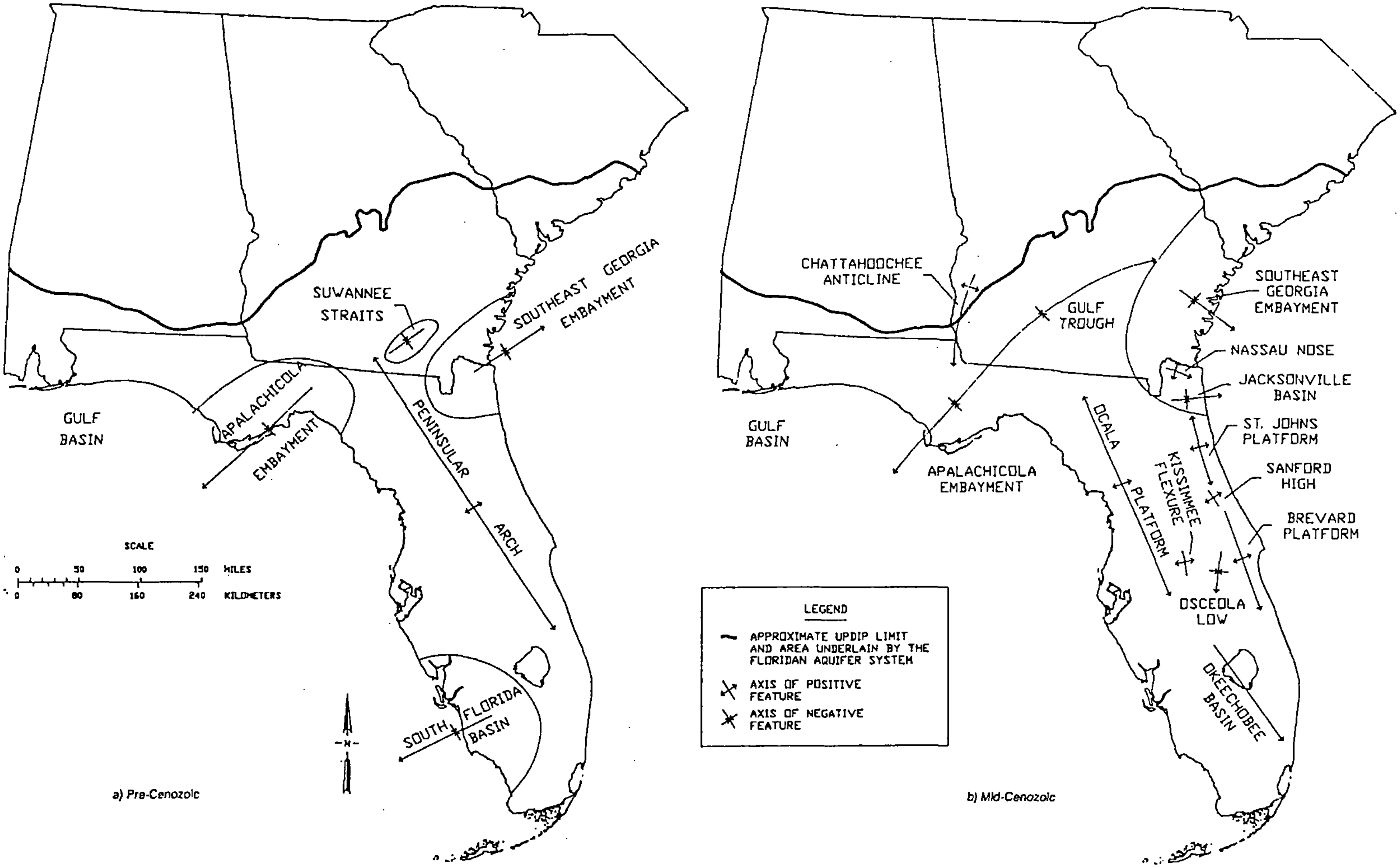


Figure 5. Structural Features of Florida
a) Pre-Cenozoic
b) Mid-Cenozoic

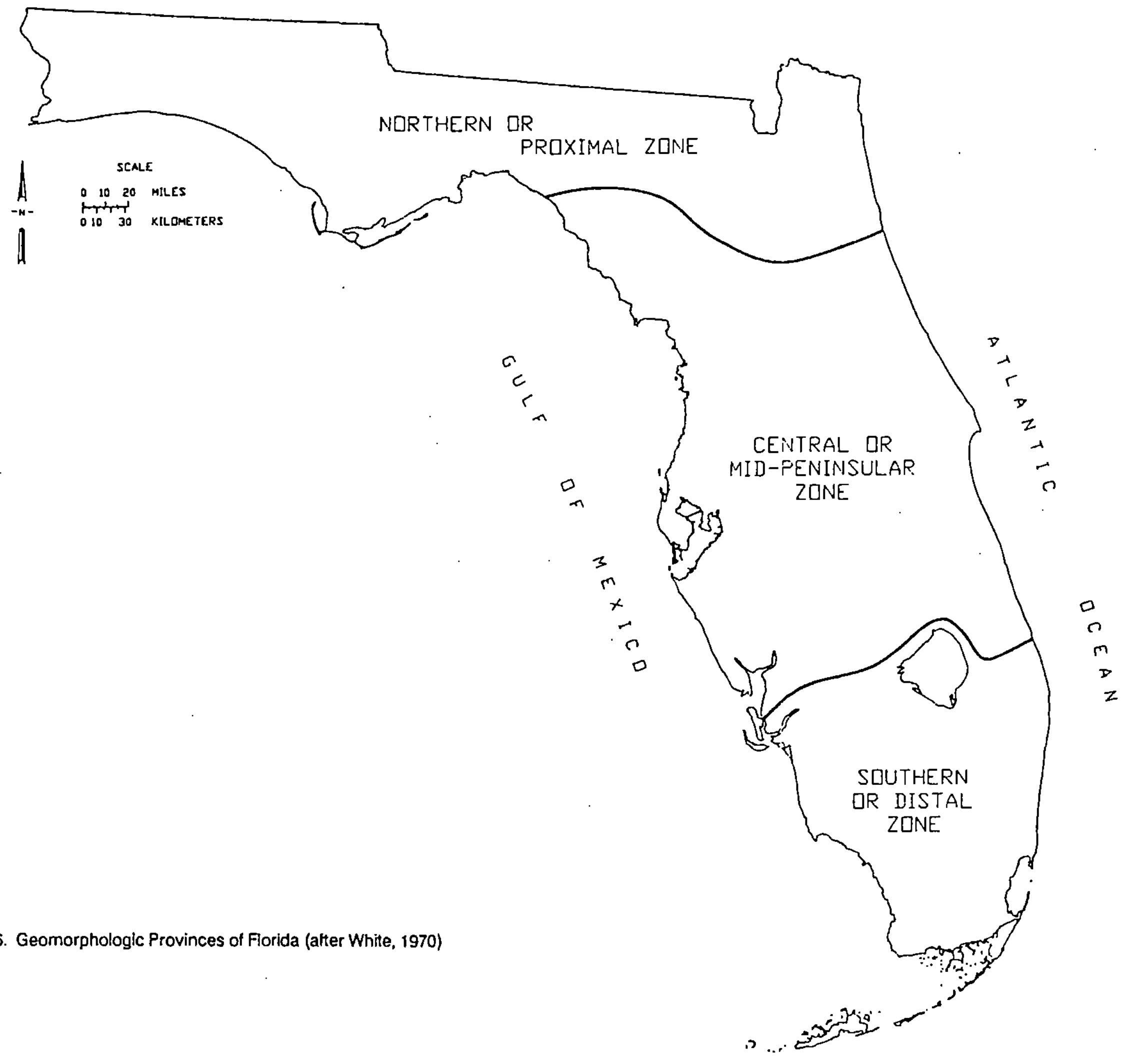


Figure 6. Geomorphologic Provinces of Florida (after White, 1970)

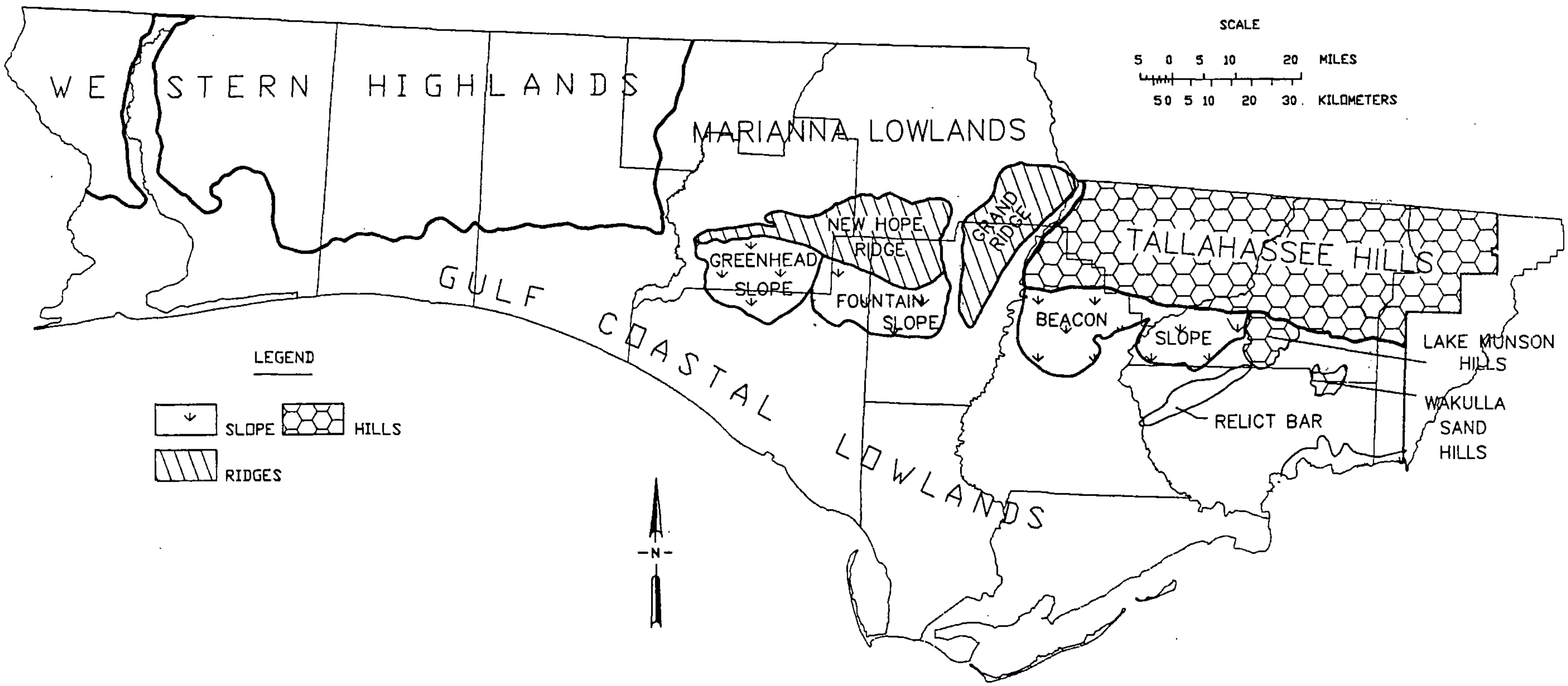


Figure 7. Geomorphologic Features of Northwest Florida Water Management District (NWFWMD) (after White, Puri and Vernon in Puri and Vernon, 1964)

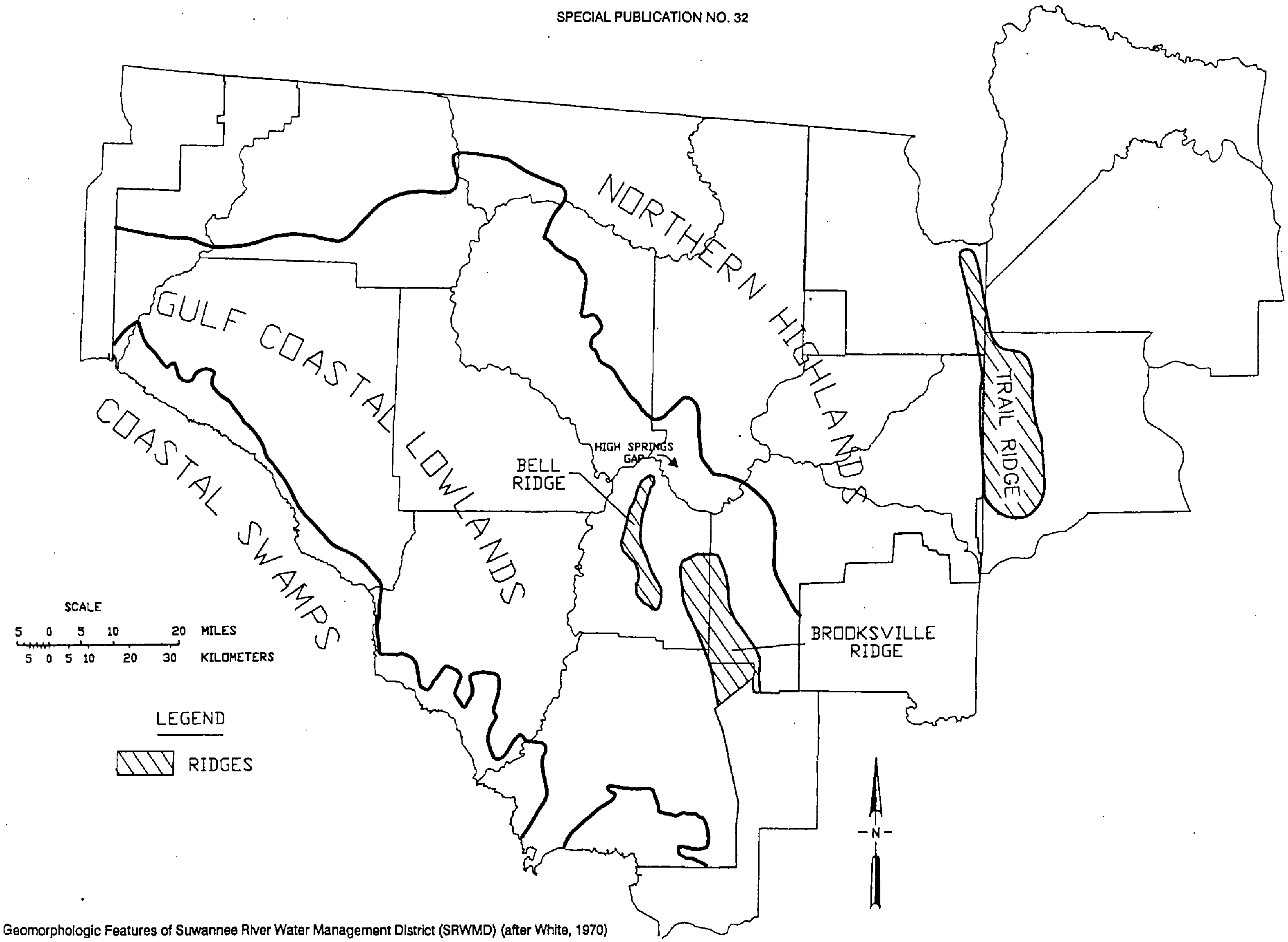


Figure 8. Geomorphologic Features of Suwannee River Water Management District (SRWMD) (after White, 1970)

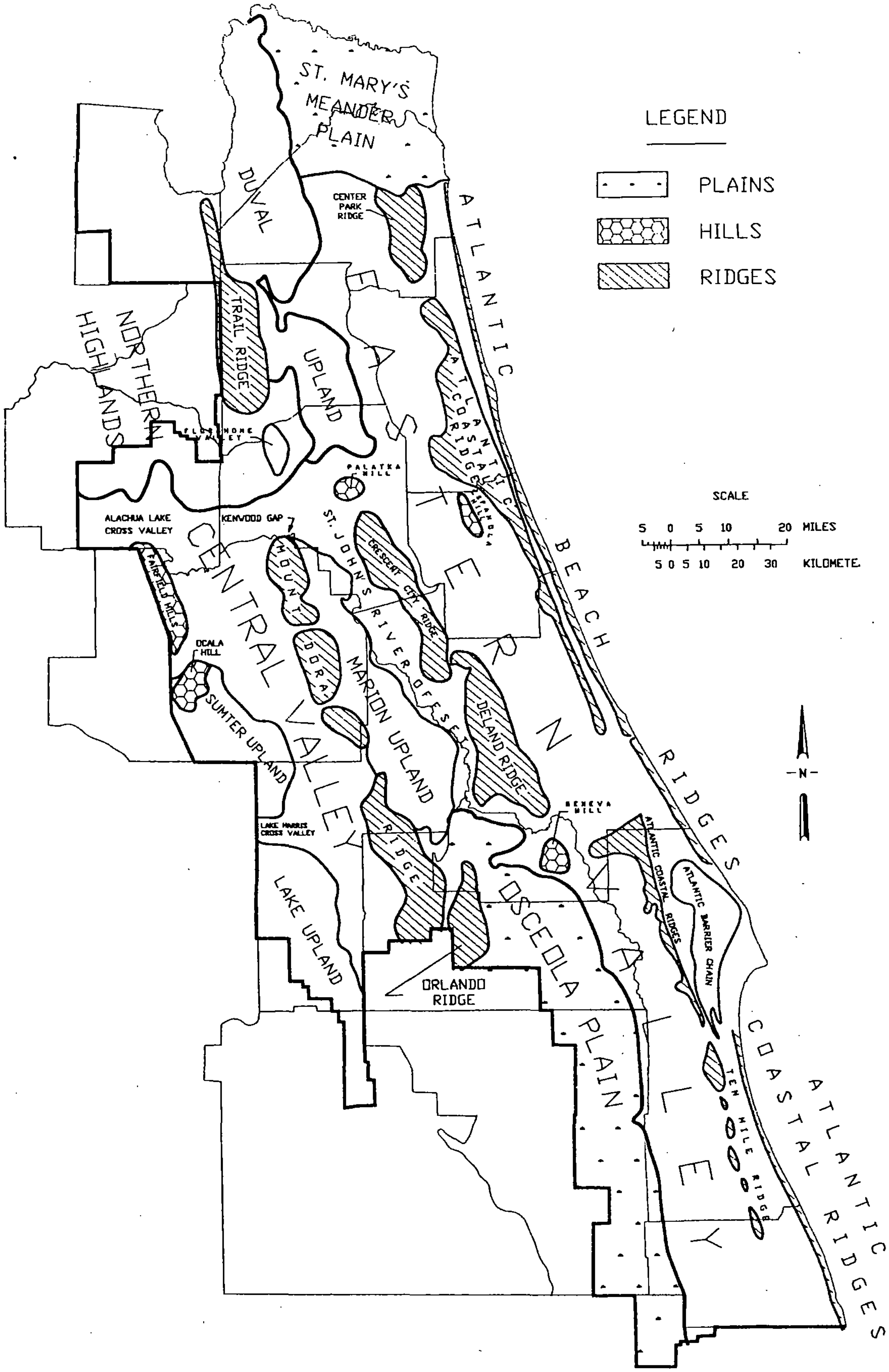


Figure 9. Geomorphologic Features of St. Johns River Water Management District (SJRWMD) (after White, 1970)

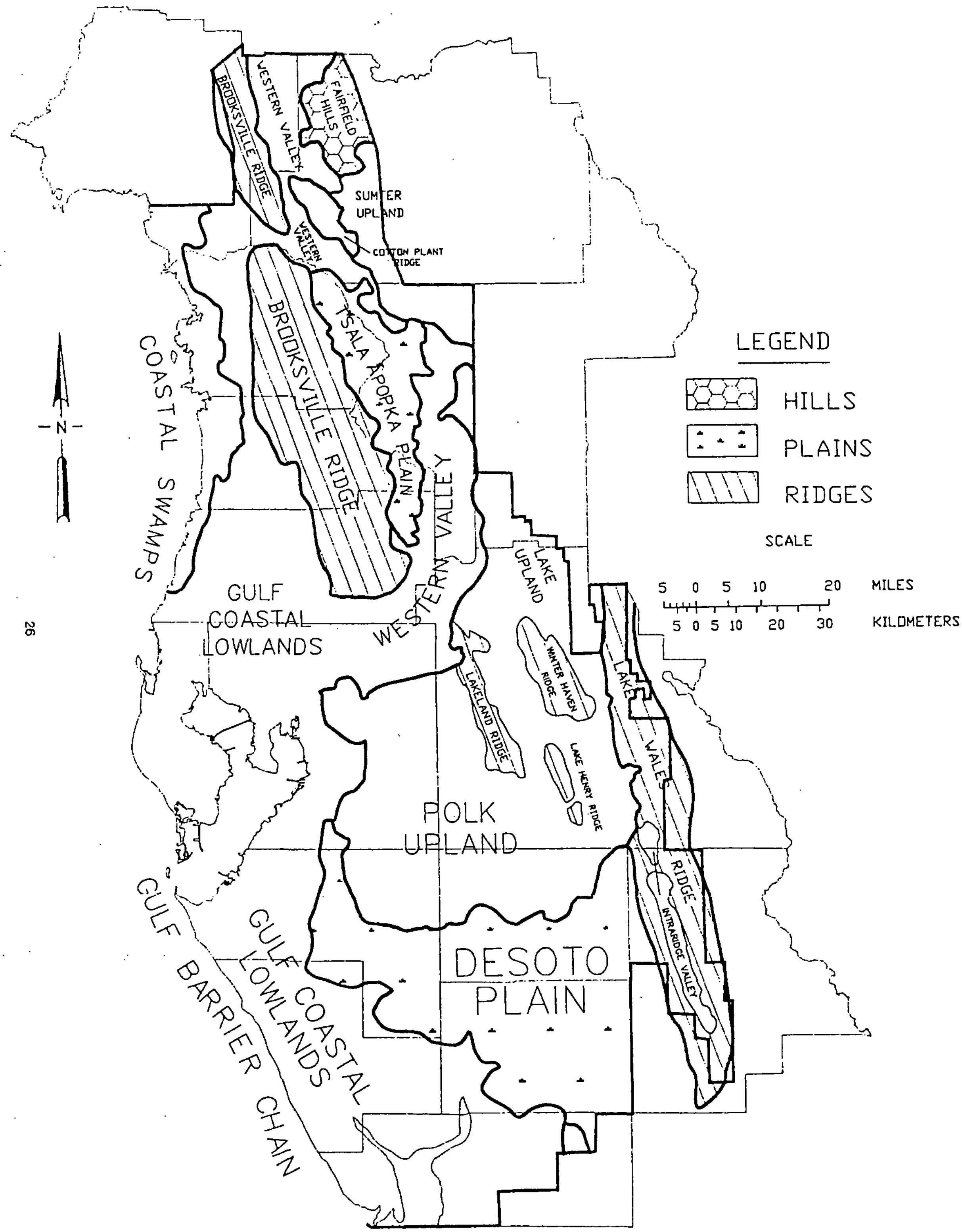


Figure 10. Geomorphologic Features of Southwest Florida Water Management District (SWFWMD) (after White, 1970)

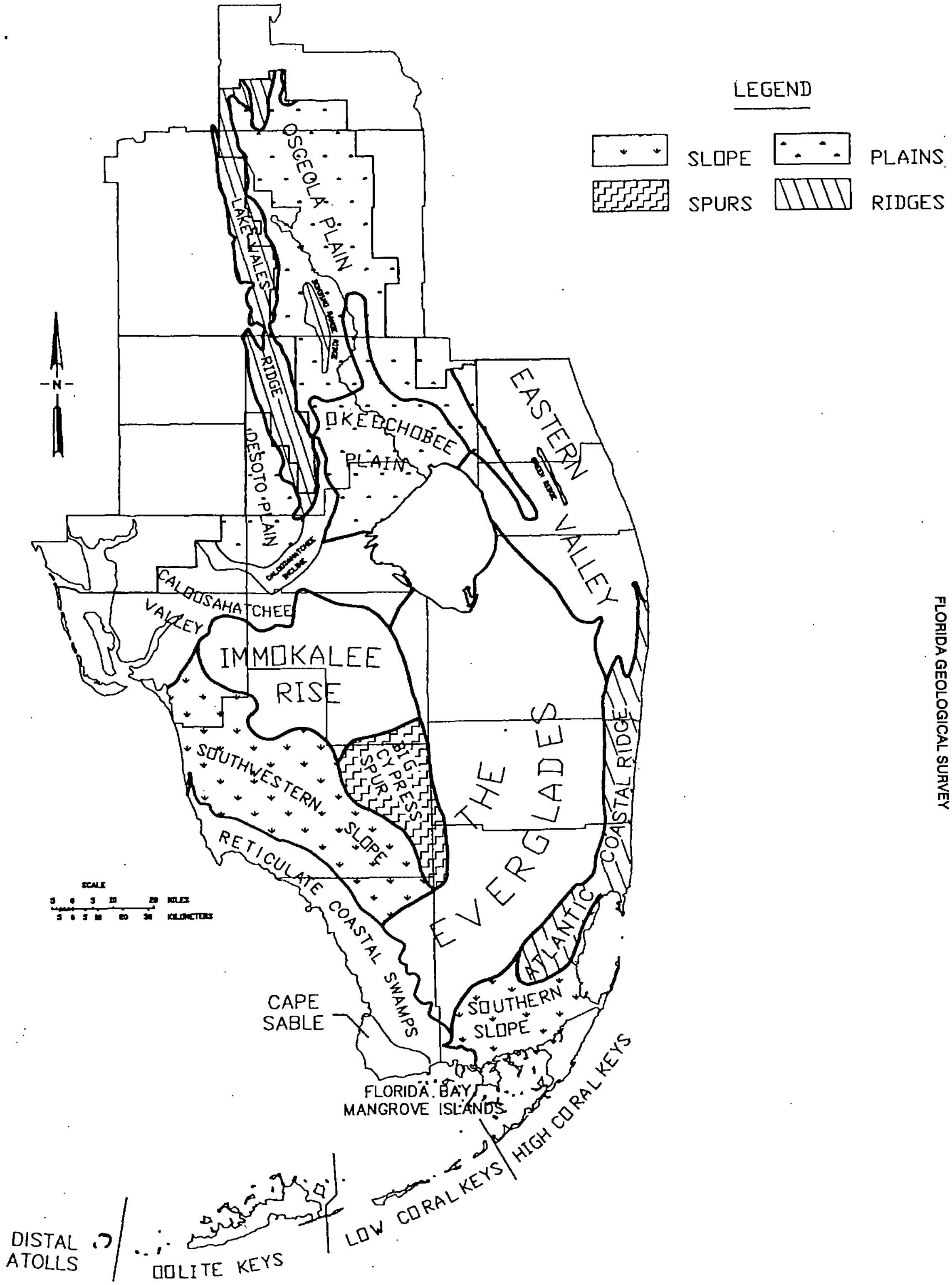


Figure 11. Geomorphologic Features of South Florida Water Management District (SFWMD) (after White, 1970)

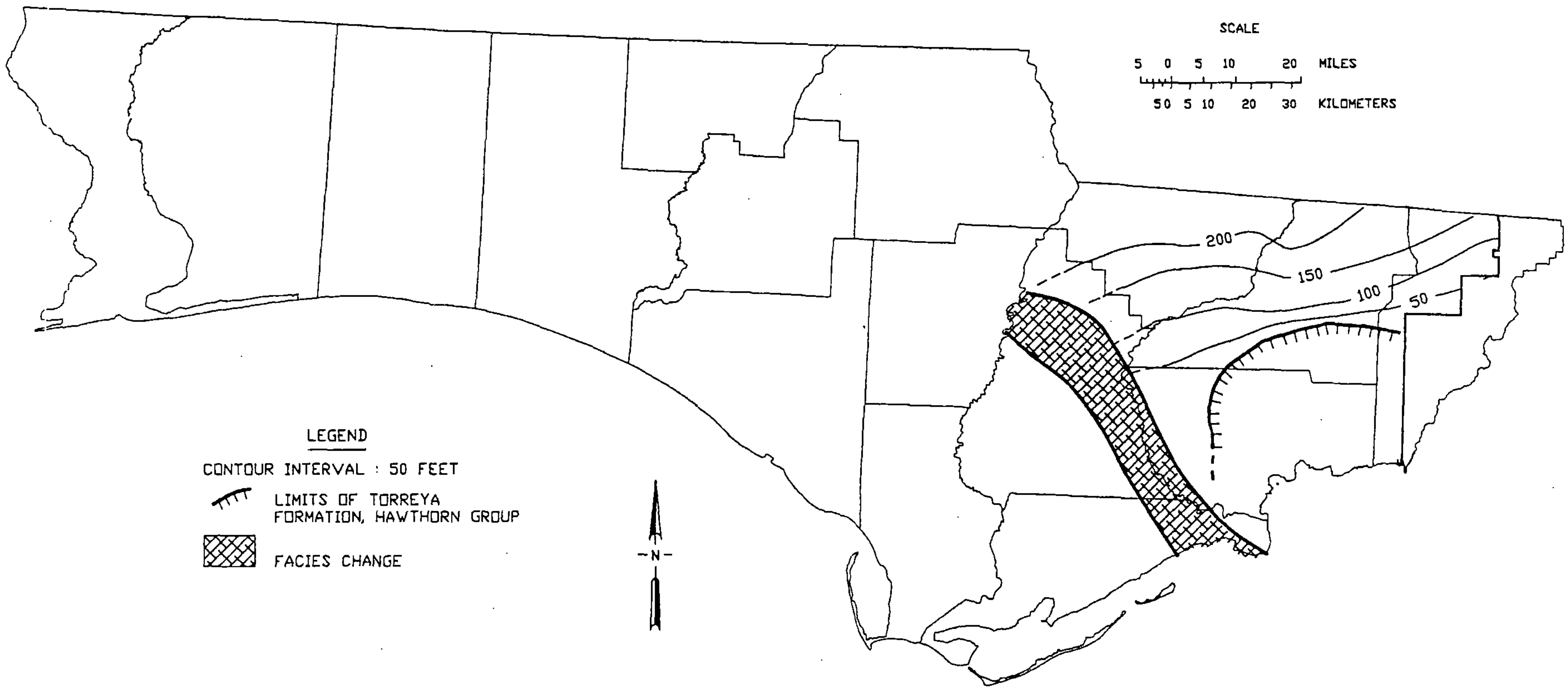


Figure 12. Top of Hawthorn Group, NWFWMD (after Scott, 1988a)

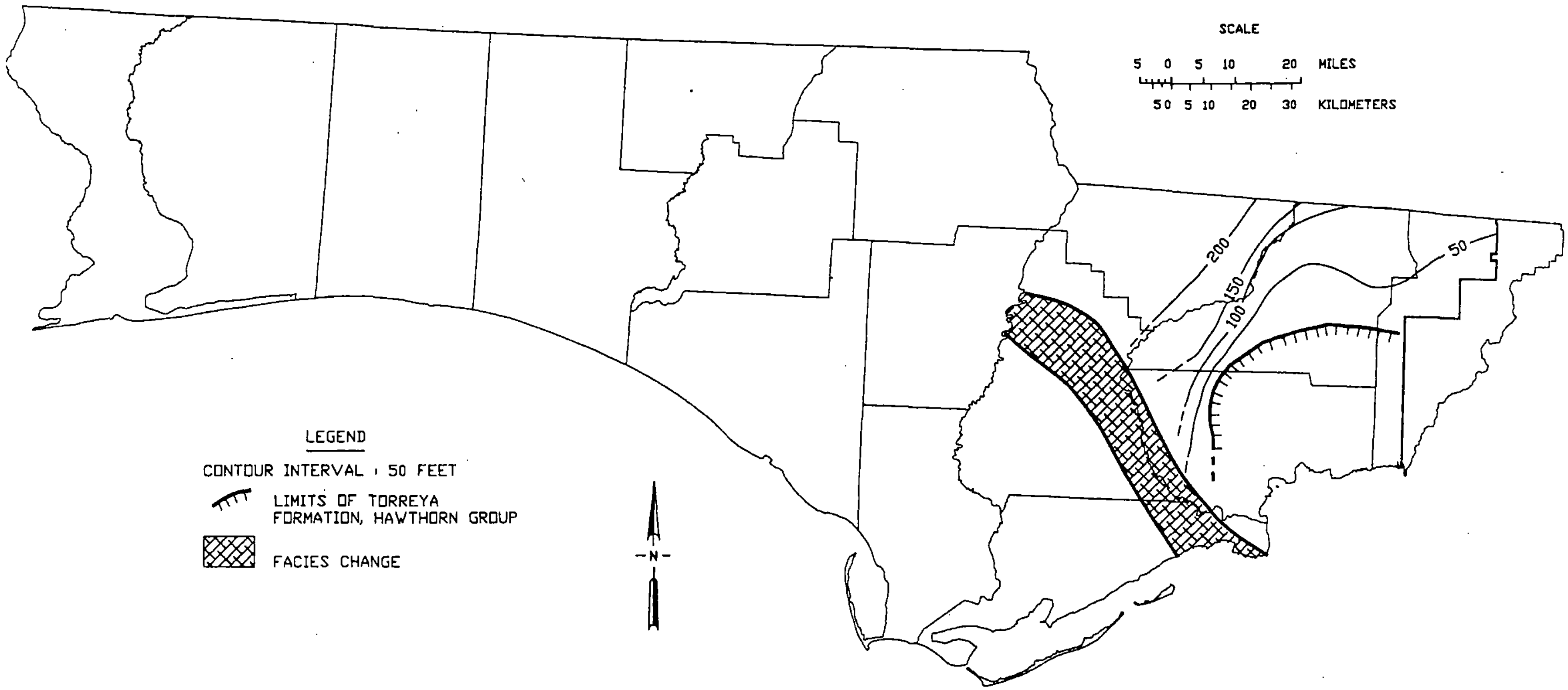


Figure 13. Isopach of Hawthorn Group, NWFWMD (after Scott, 1988a)

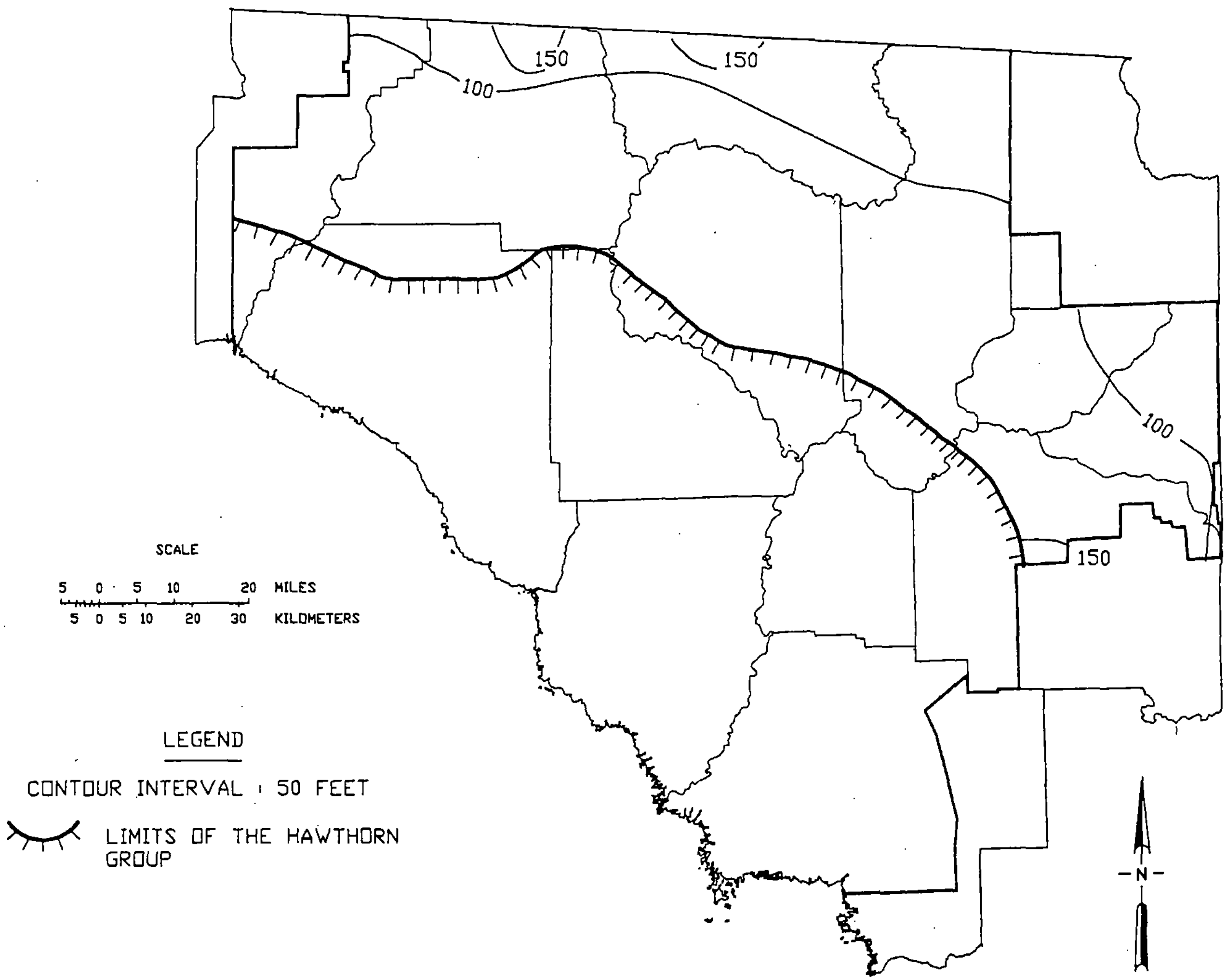


Figure 14. Top of Hawthorn Group, SRWMD (after Scott, 1988a)

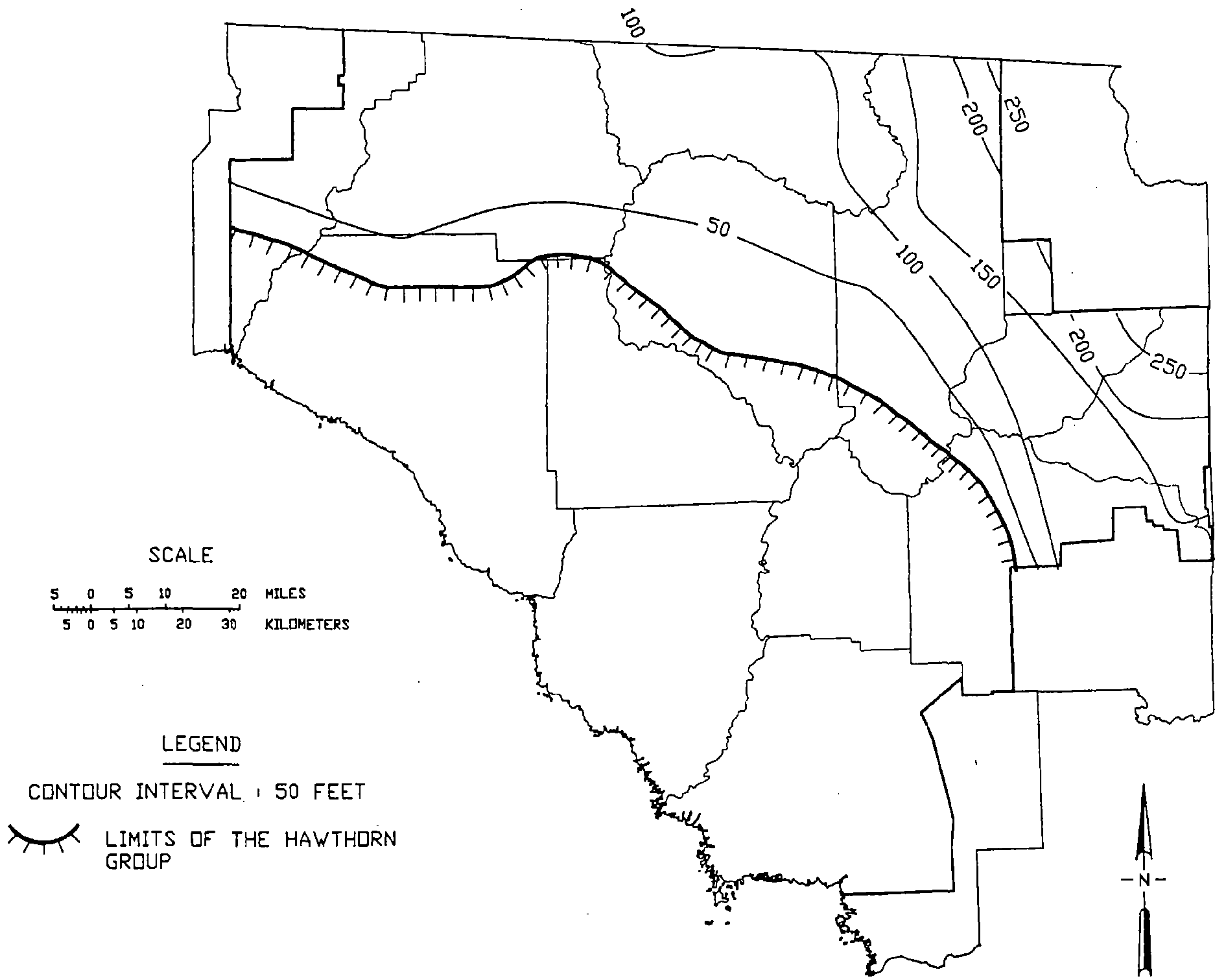


Figure 15. Isopach of Hawthorn Group, SRWMD (after Scott, 1988a)

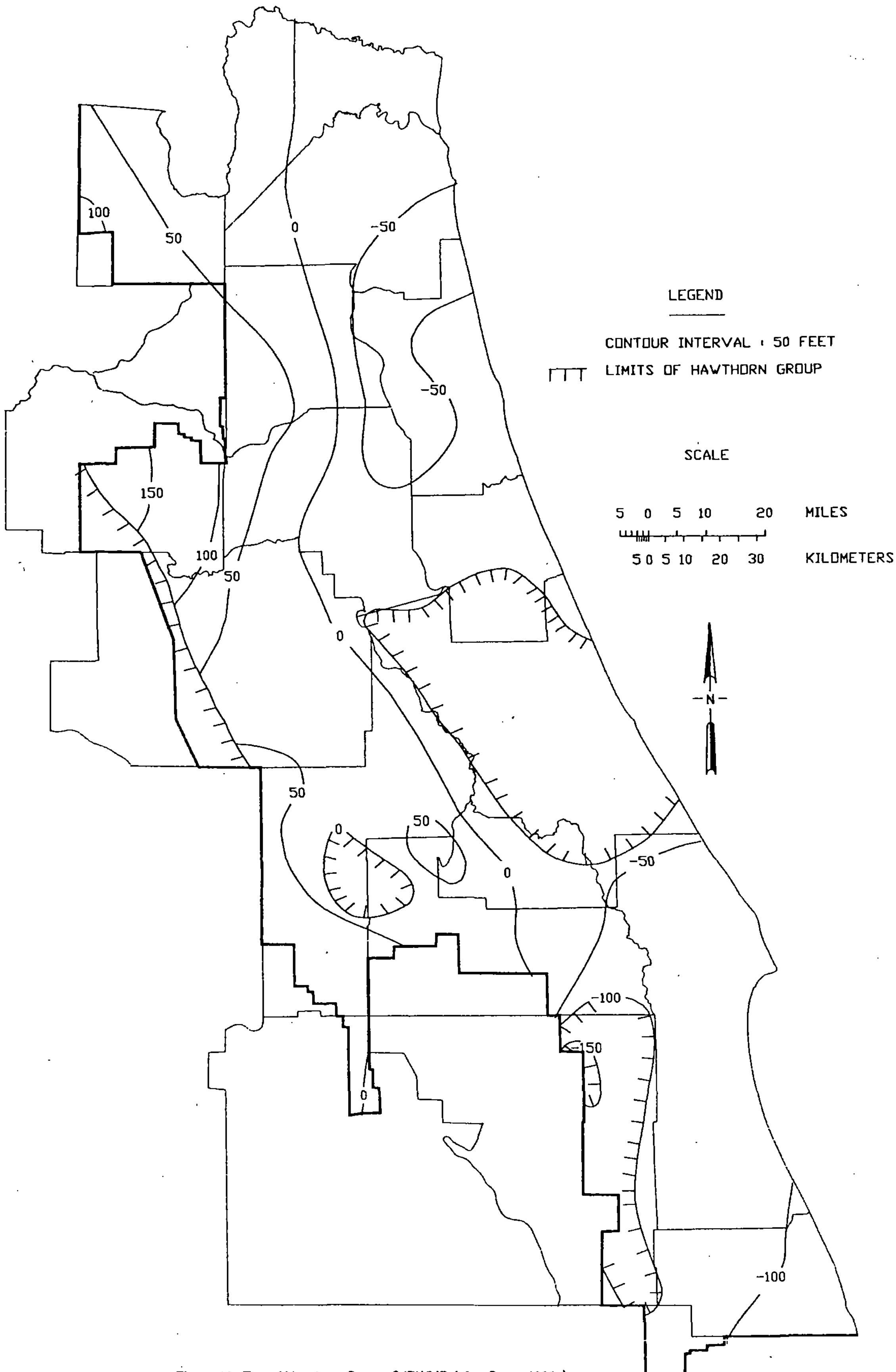


Figure 16. Top of Hawthorn Group, SJRWMD (after Scott, 1988a)

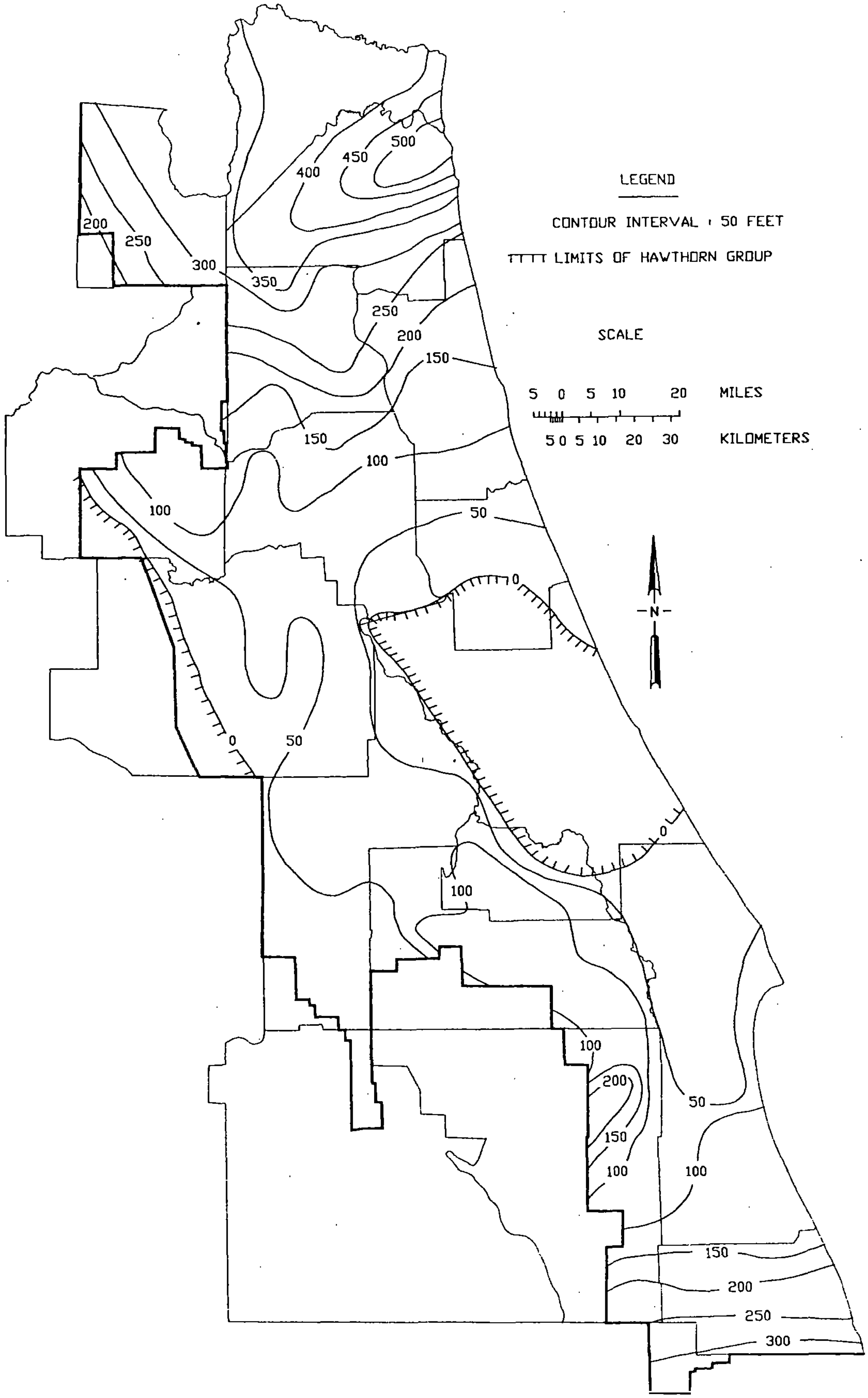


Figure 17. Isopach of Hawthorn Group, SJRWMD (after Scott, 1988a)

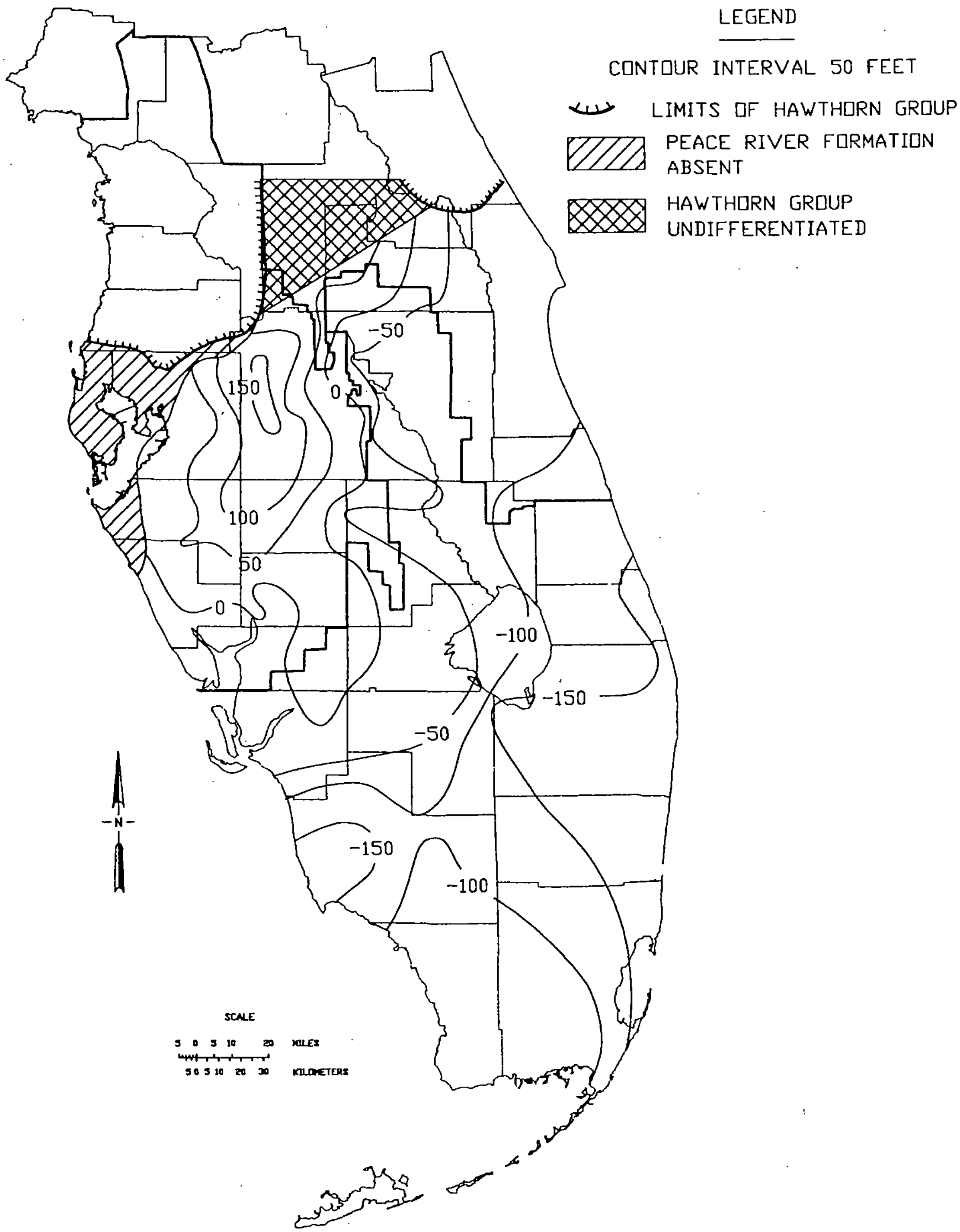


Figure 18. Top of Hawthorn Group, SWFWMD and SFWMD (after Scott, 1988a)

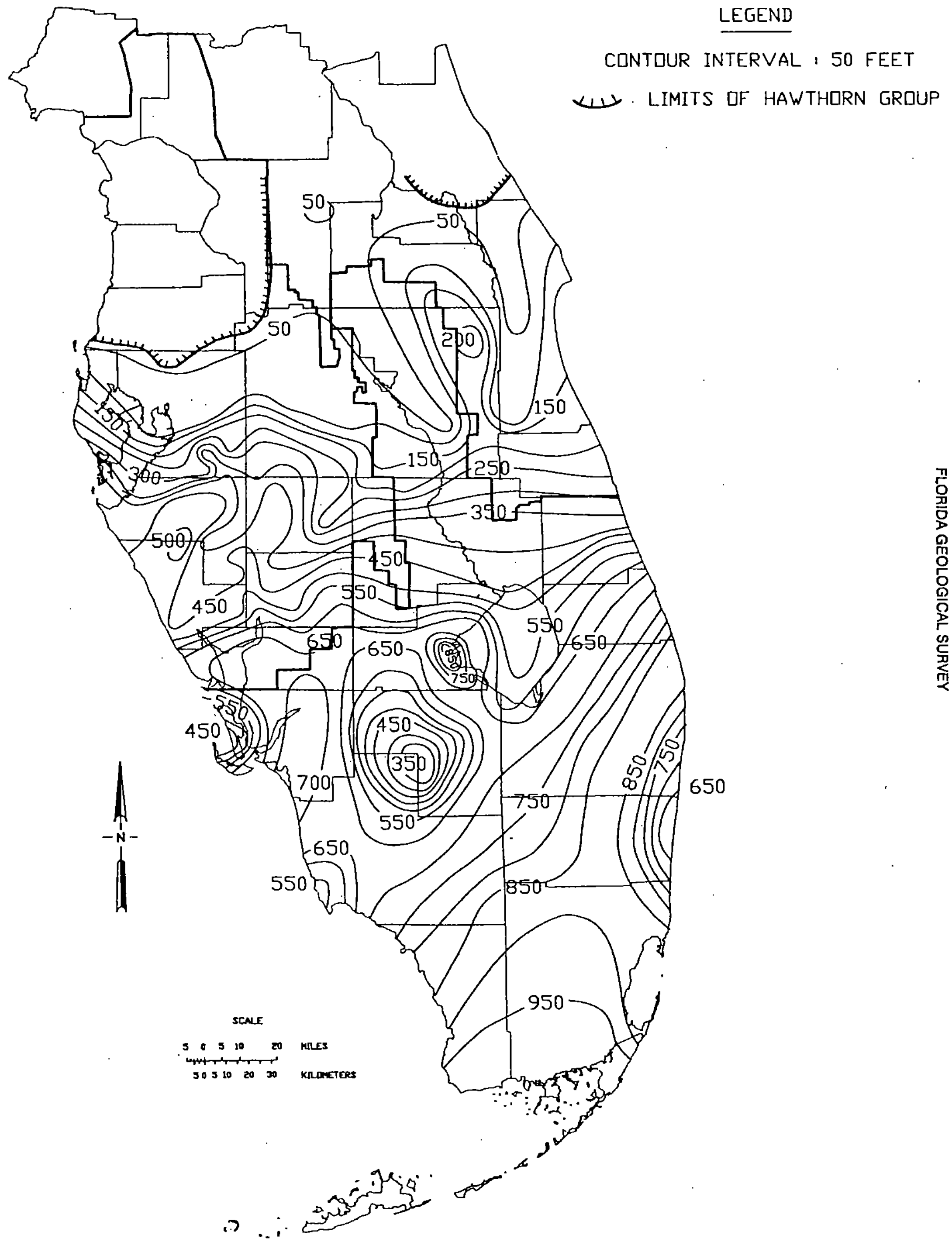


Figure 19. Isopach of Hawthorn Group, SWFWMD and SFWMD (after Scott, 1988a)

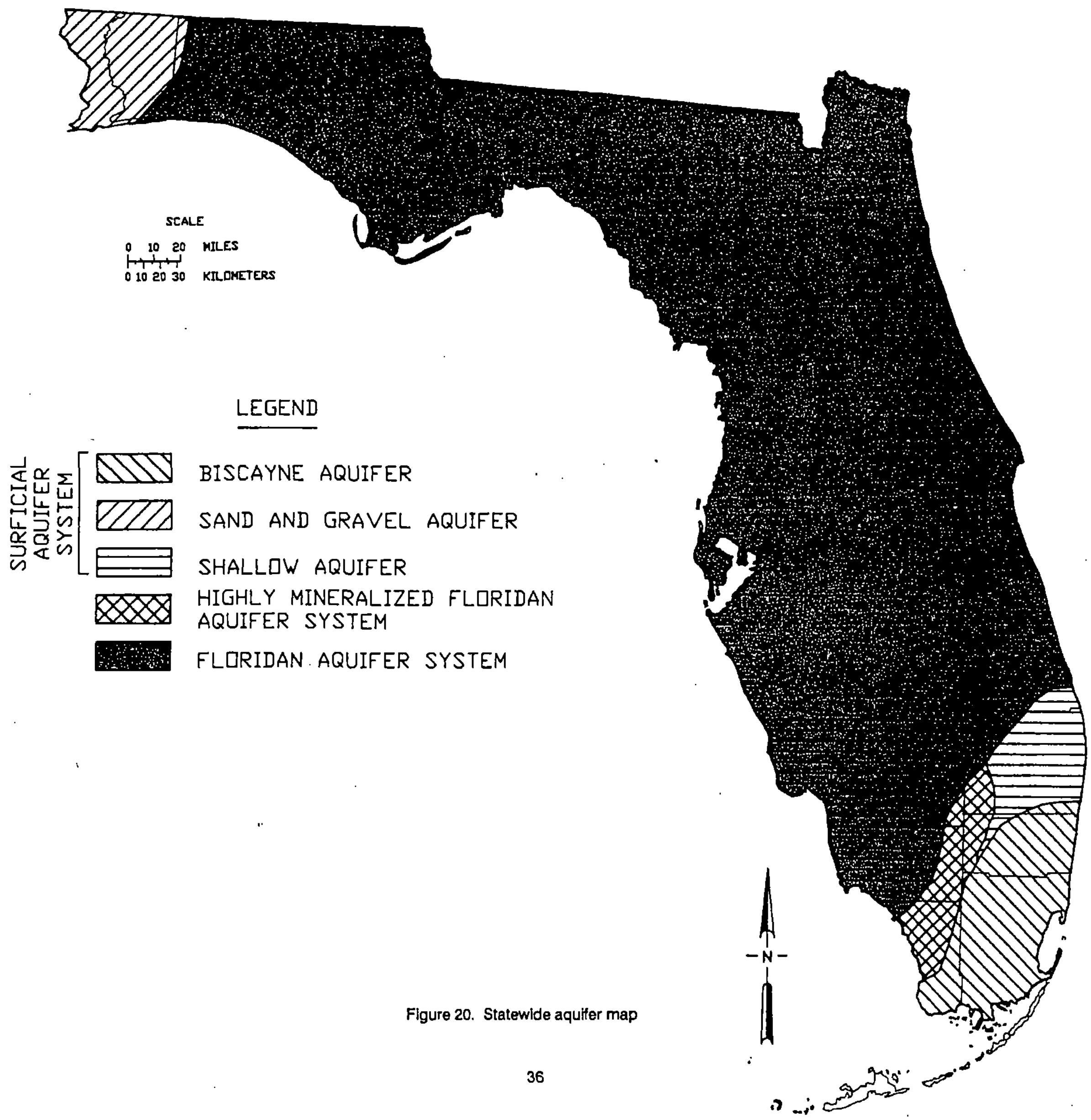


Figure 20. Statewide aquifer map

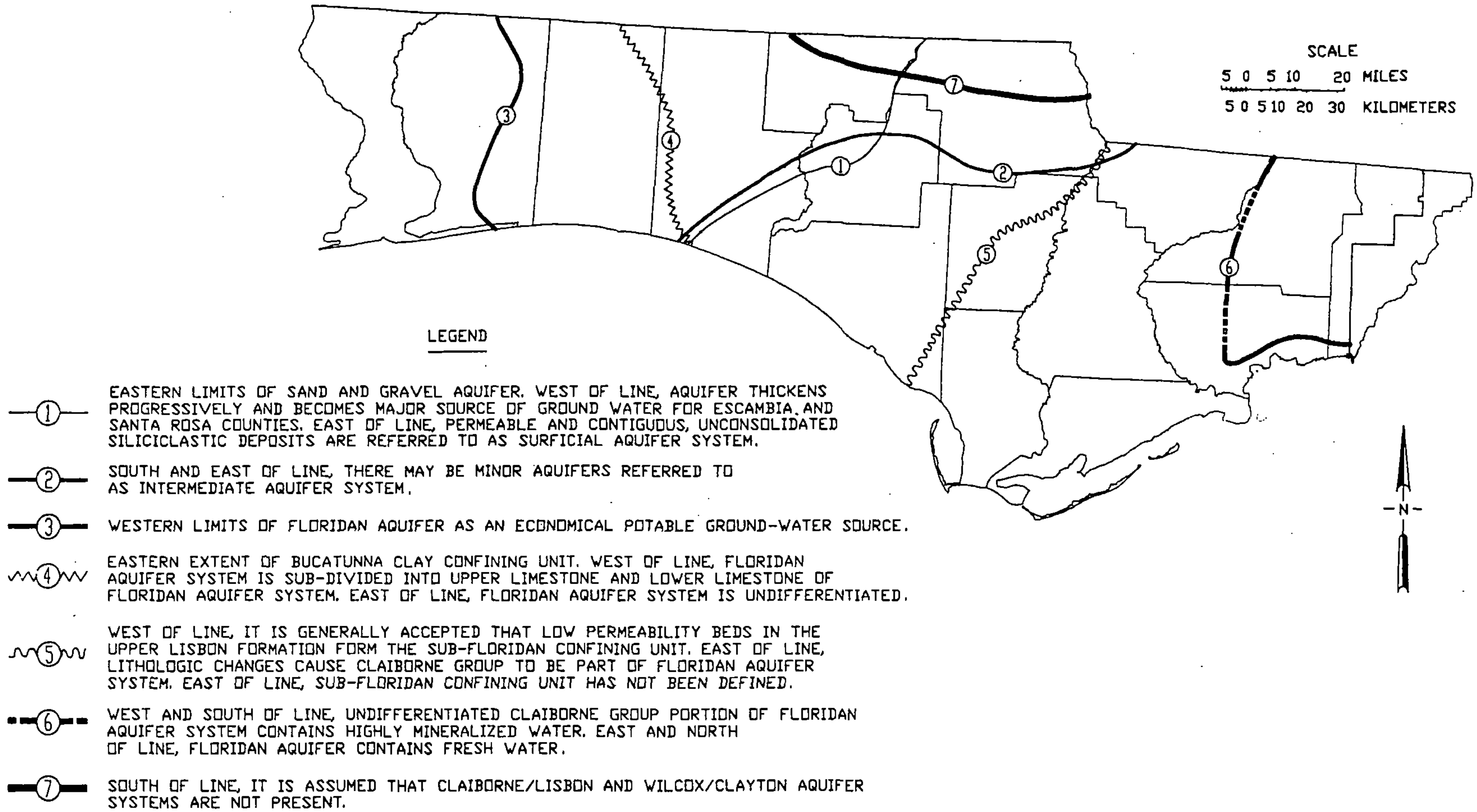


Figure 21. Occurrence and extent of ground water in NWFWMD

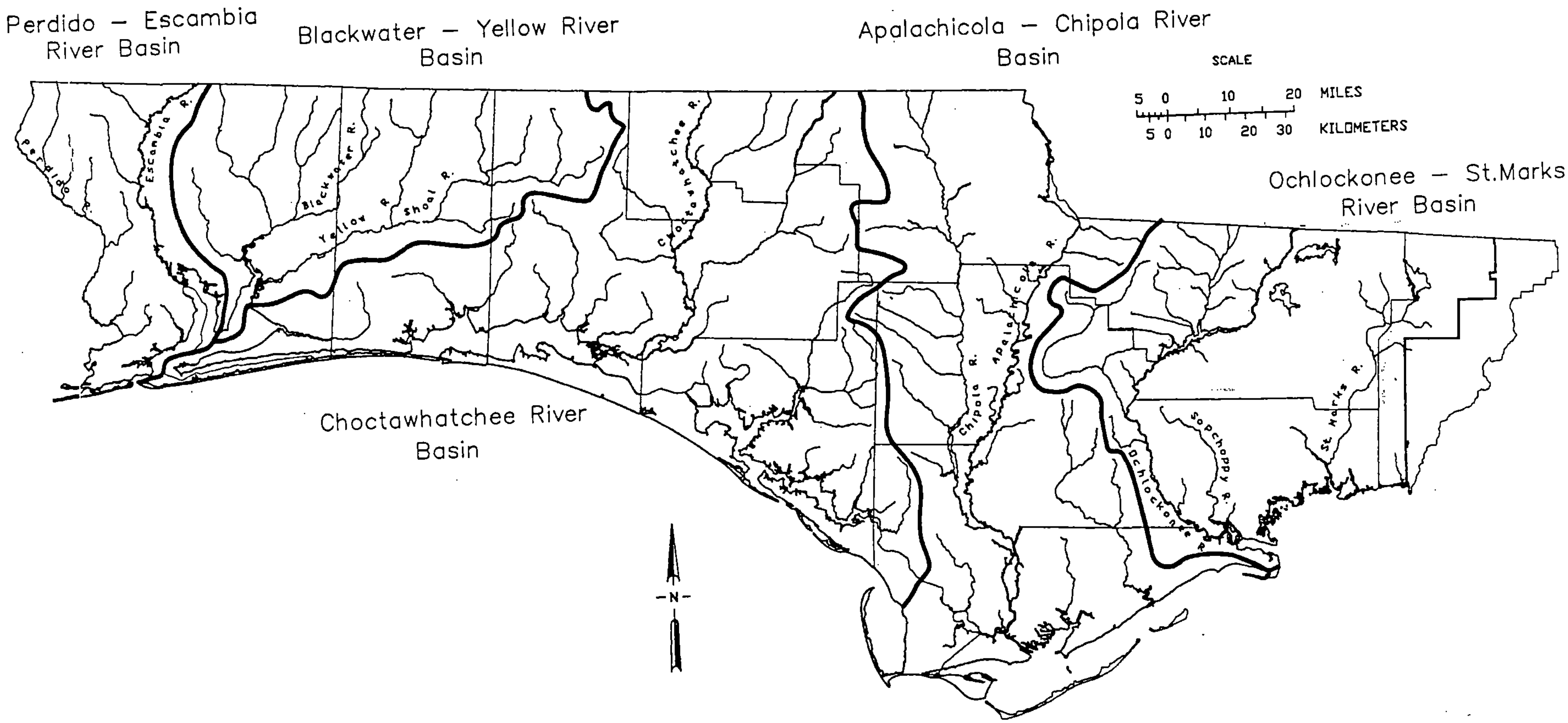


Figure 22. Surface-water basins, NWFWMD

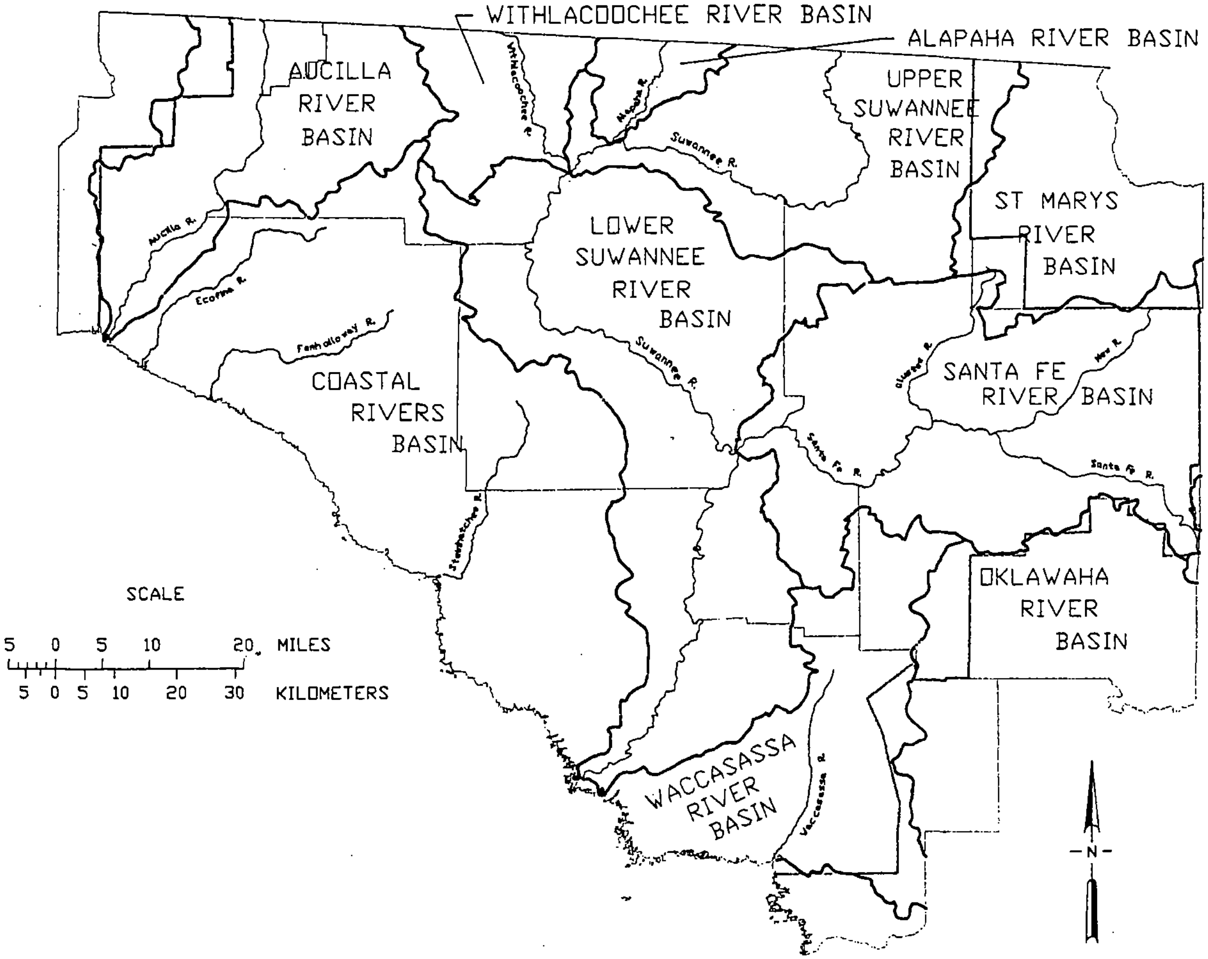


Figure 23. Surface-water basins, SRWMD

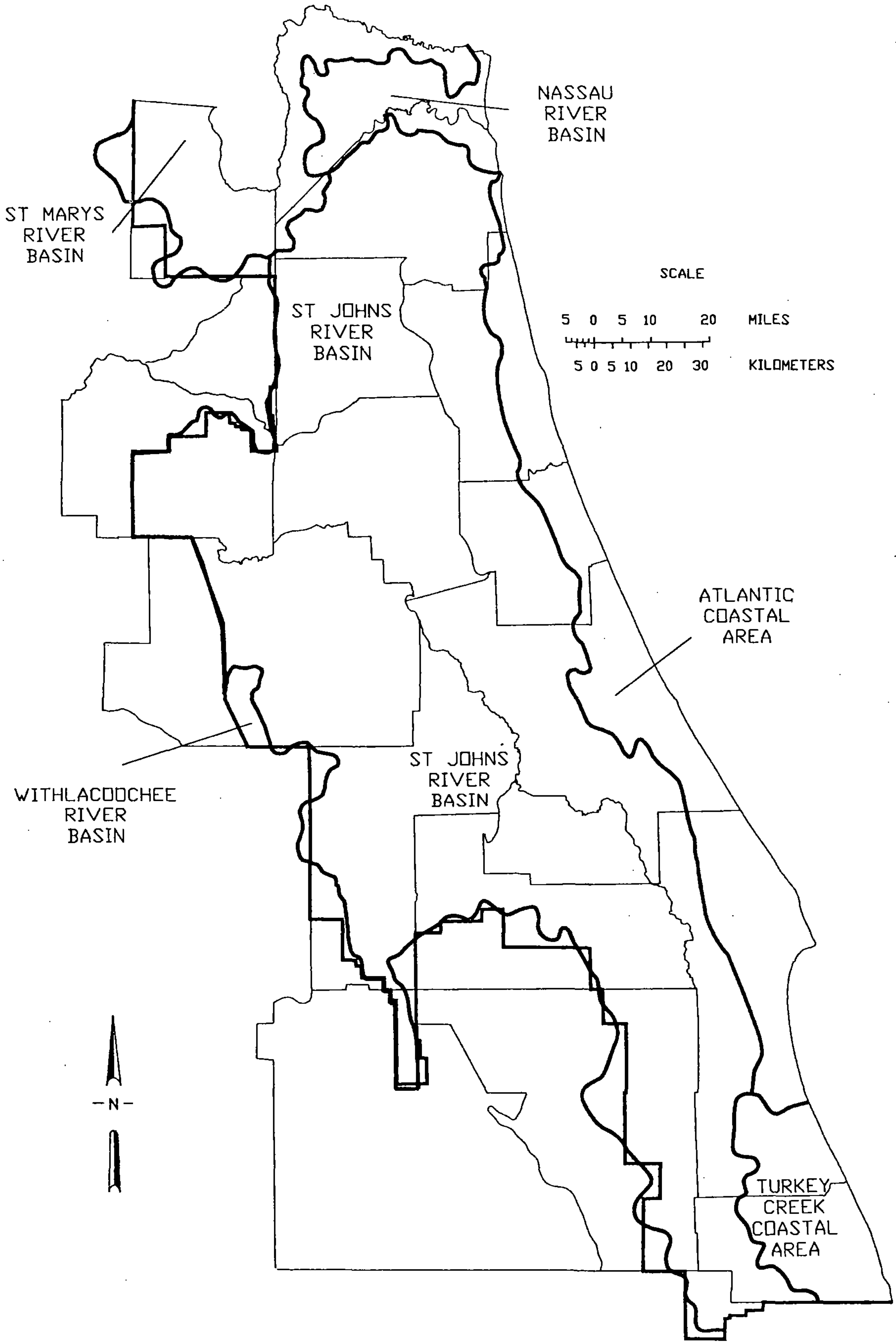


Figure 24. Surface-water basins, SJRWMD

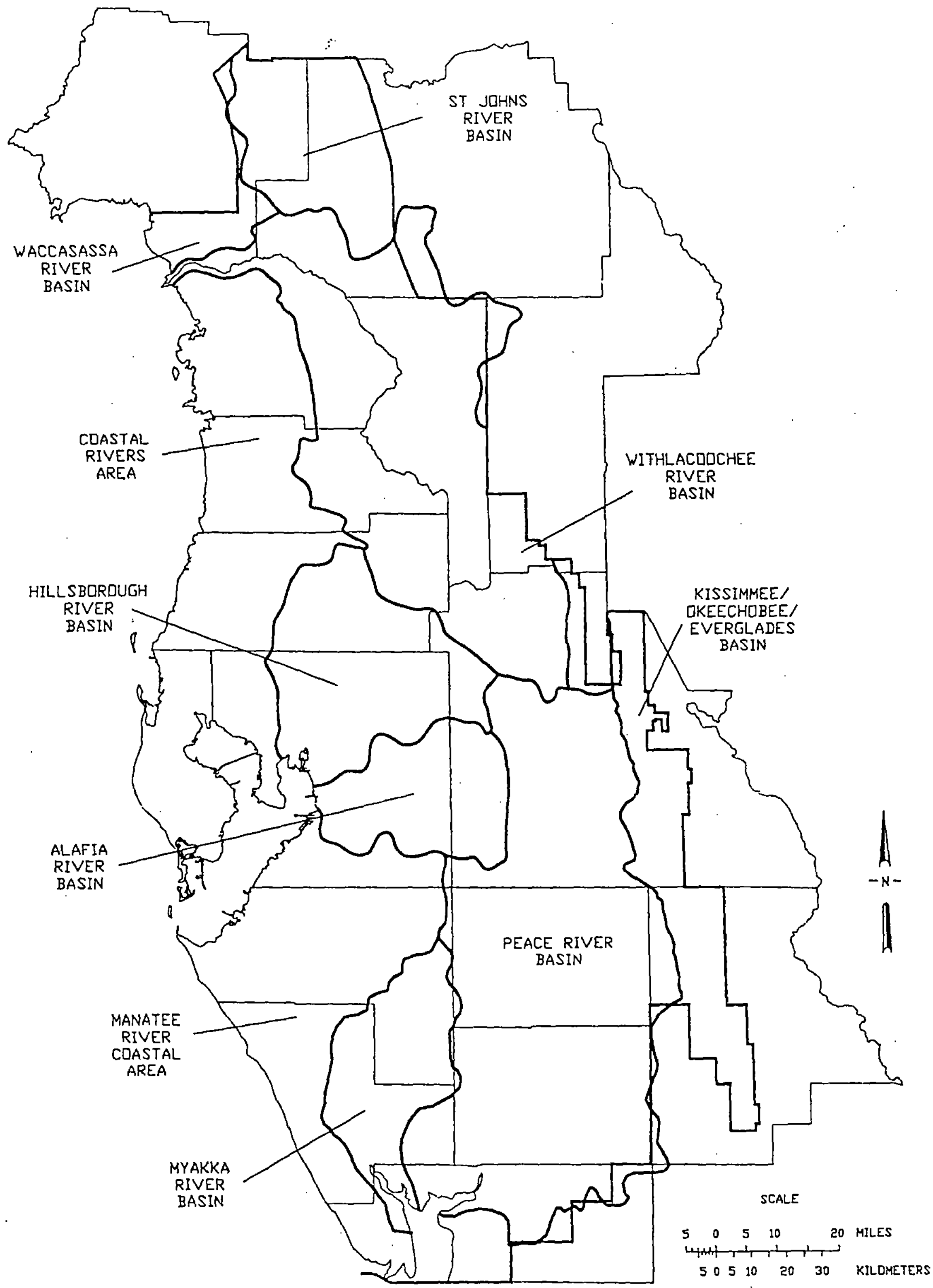


Figure 25. Surface-water basins, SWFWMD

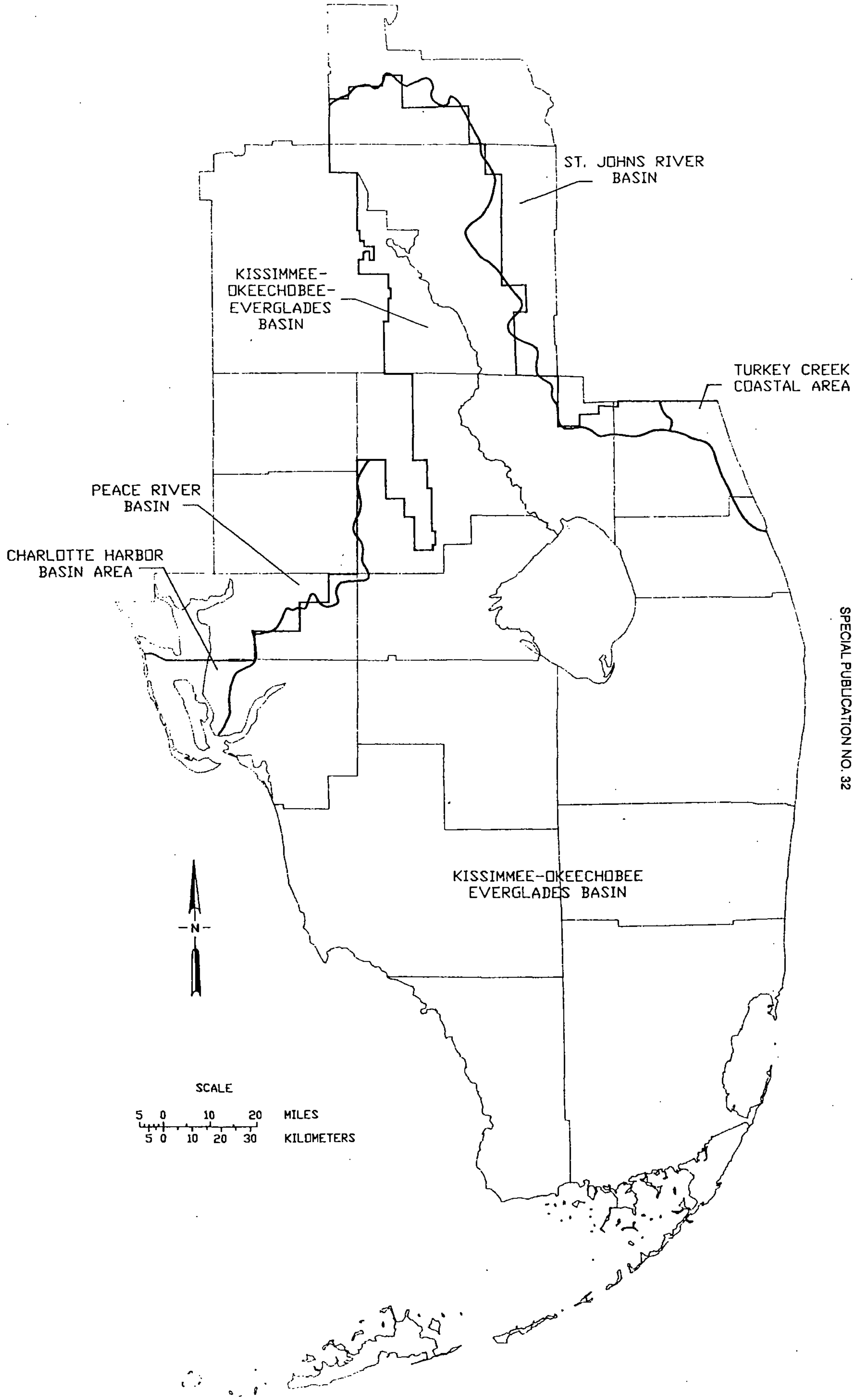


Figure 26. Surface-water basins, SFWMD

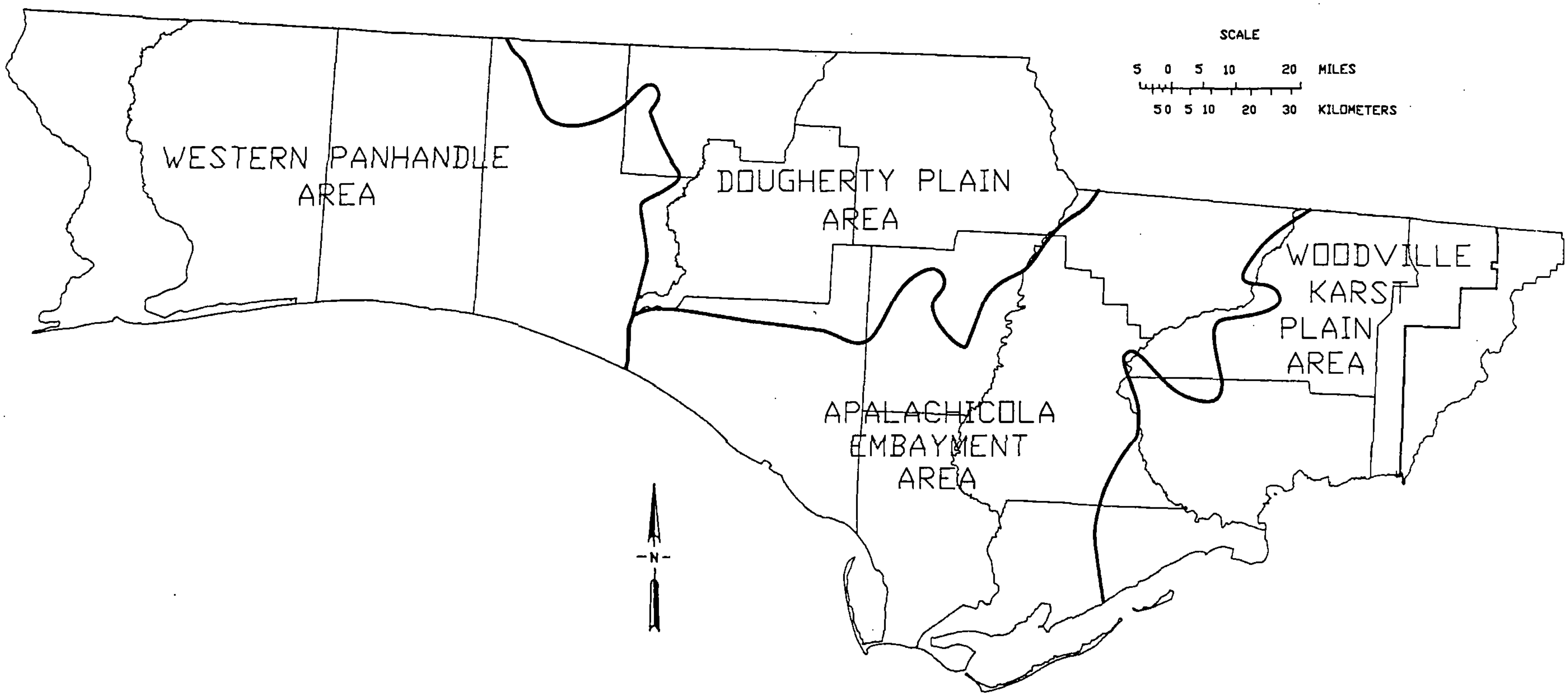


Figure 27. Ground-water areas, NWFWMD

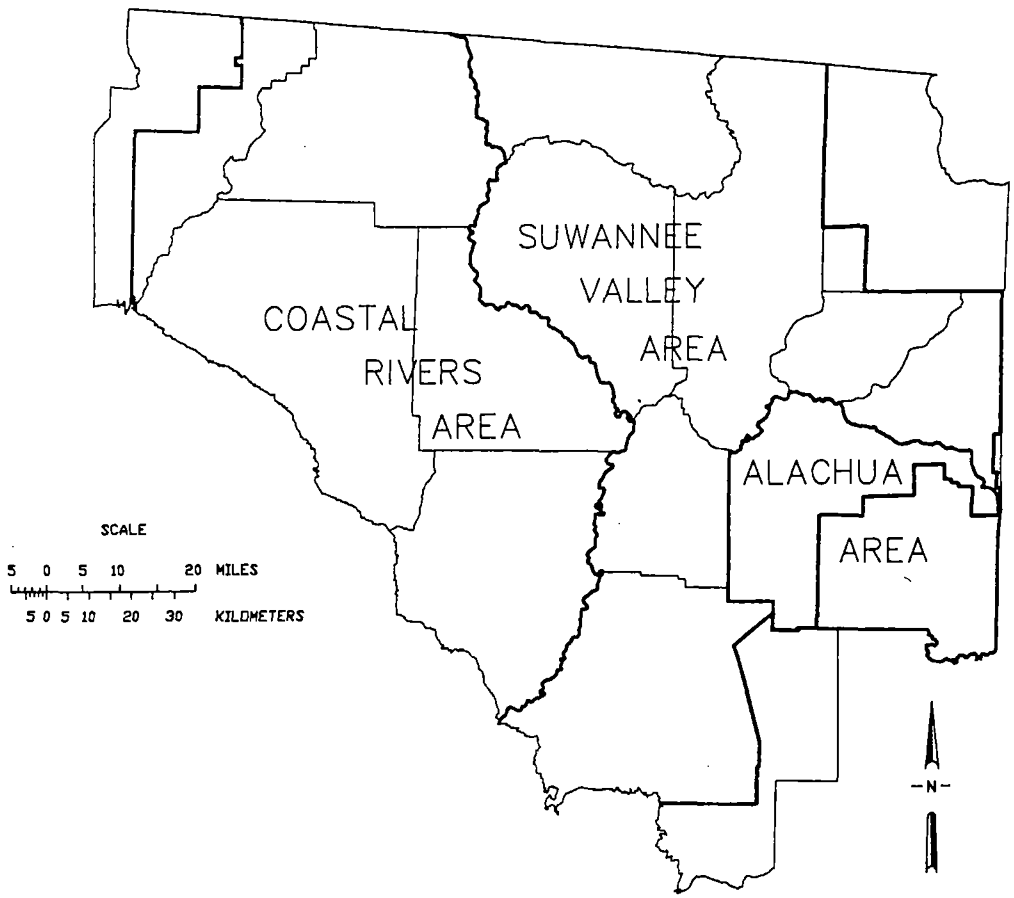


Figure 28. Ground-water areas, SRWMD

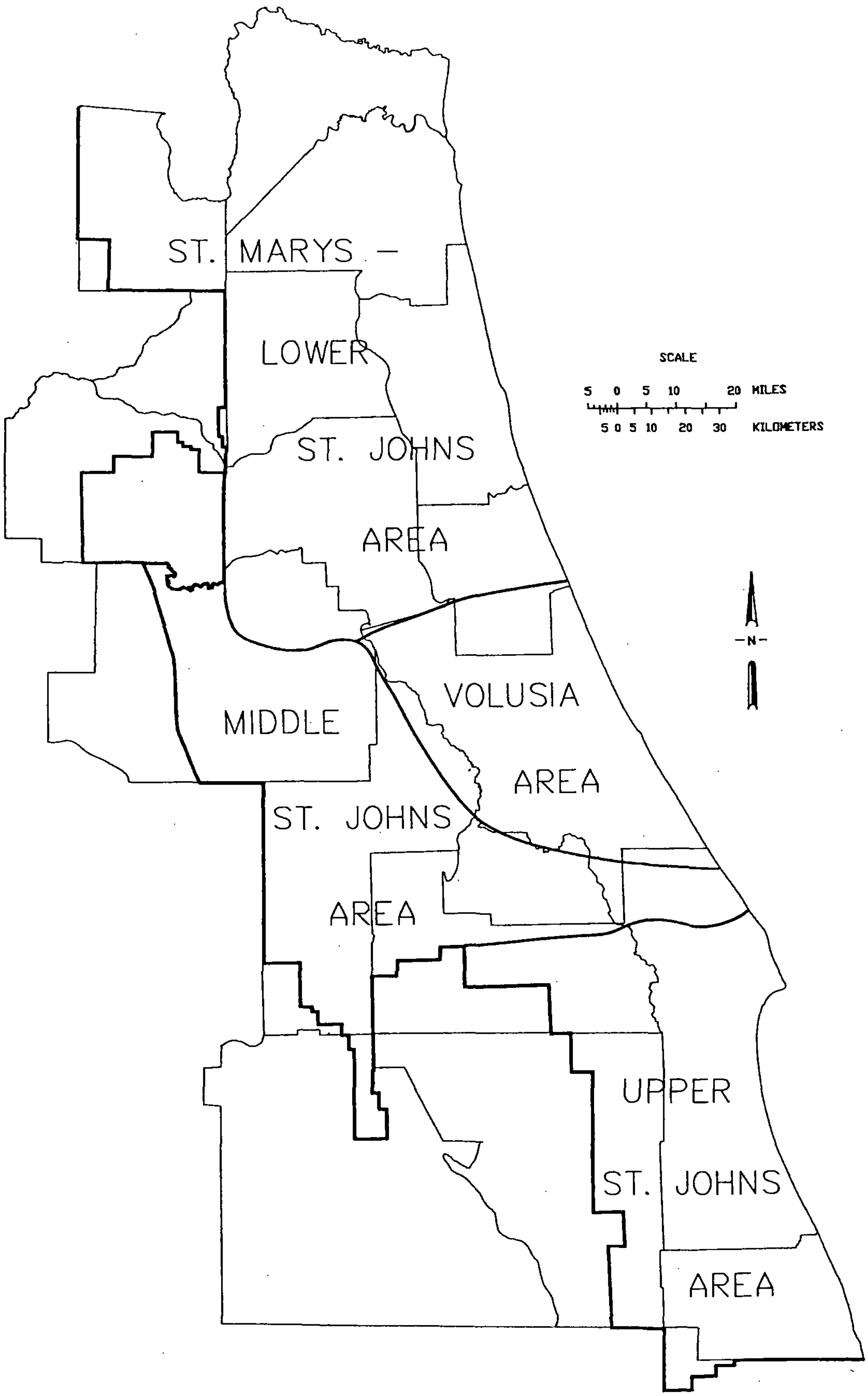


Figure 29. Ground-water areas, SJRWMD

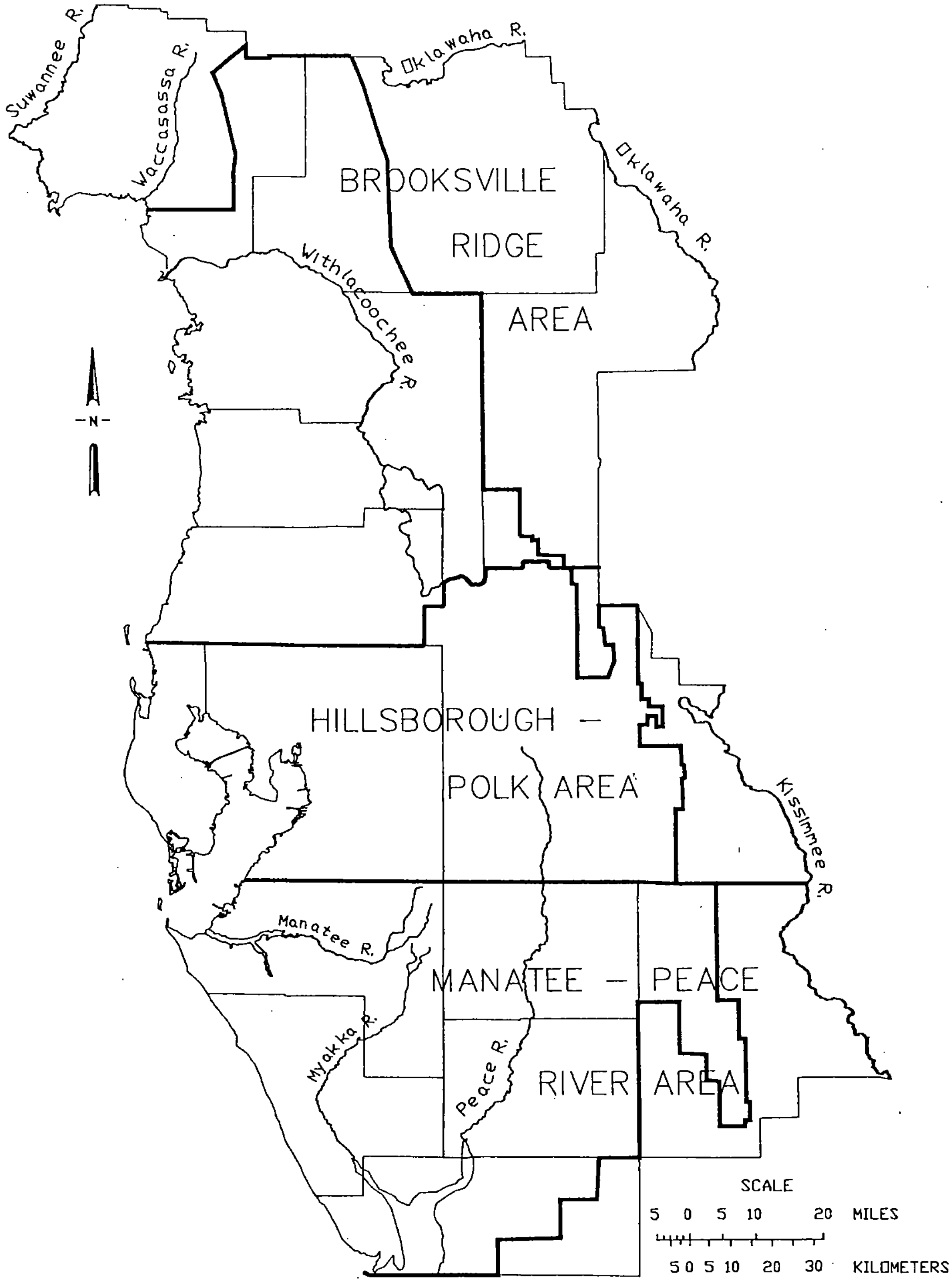


Figure 30. Ground-water areas, SWFWMD

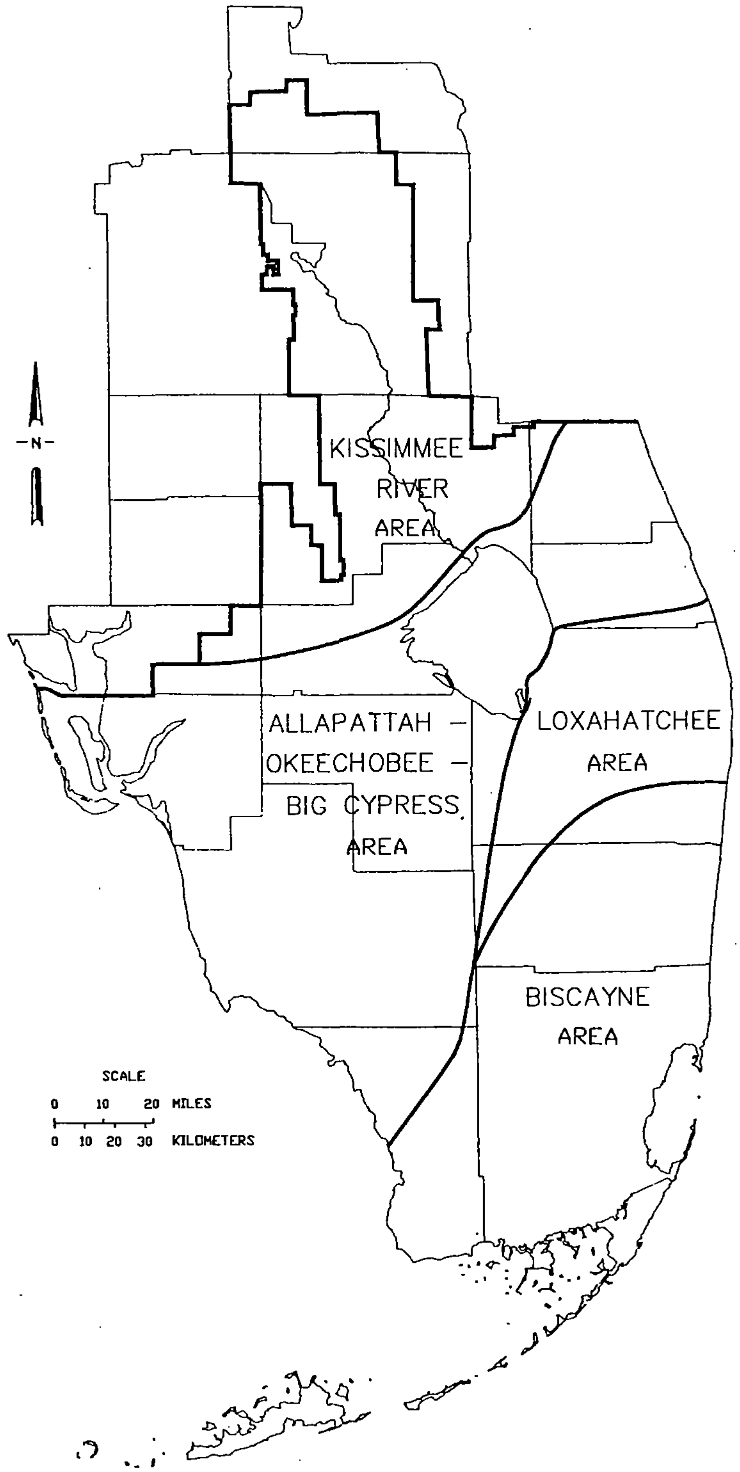


Figure 31. Ground-water areas, SFWMD

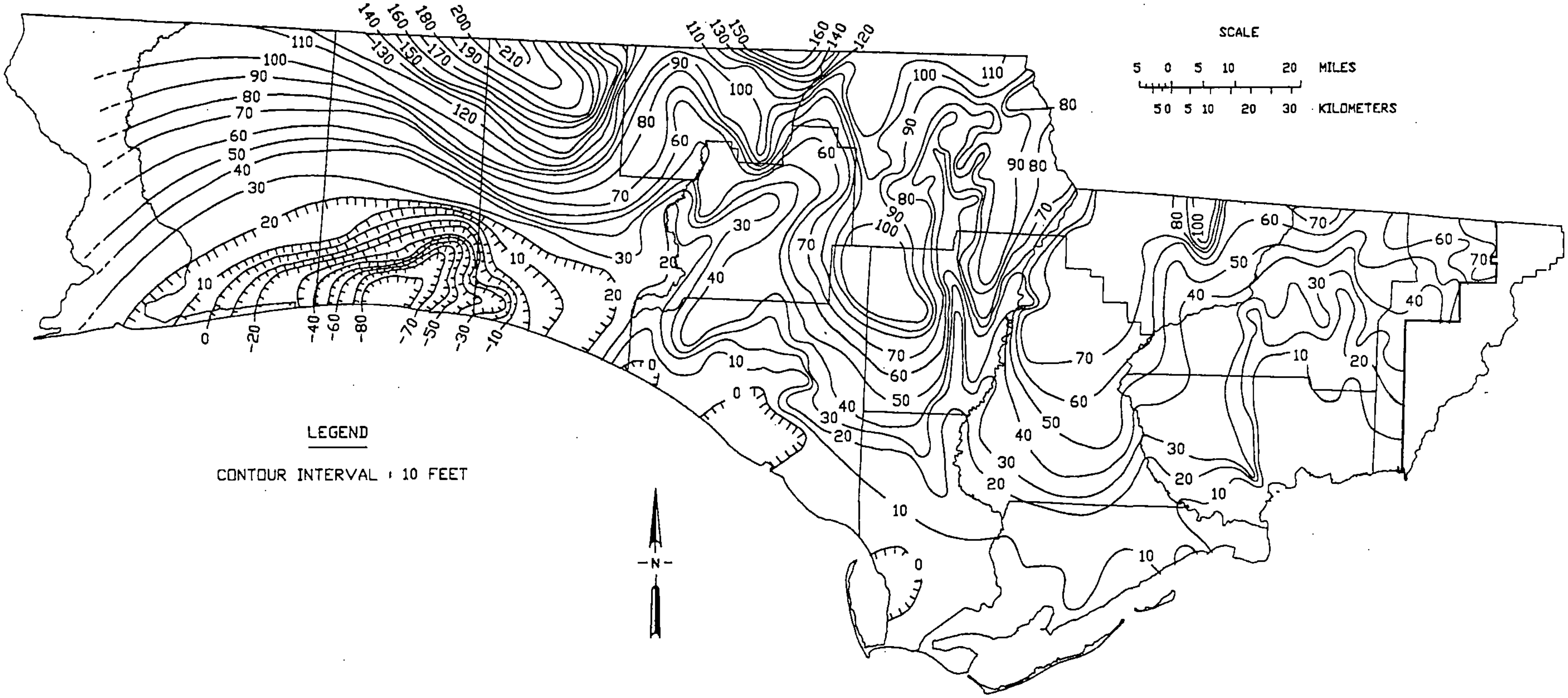


Figure 32. Floridan aquifer system potentiometric surface, NWFWMD (modified from Wagner, 1989)

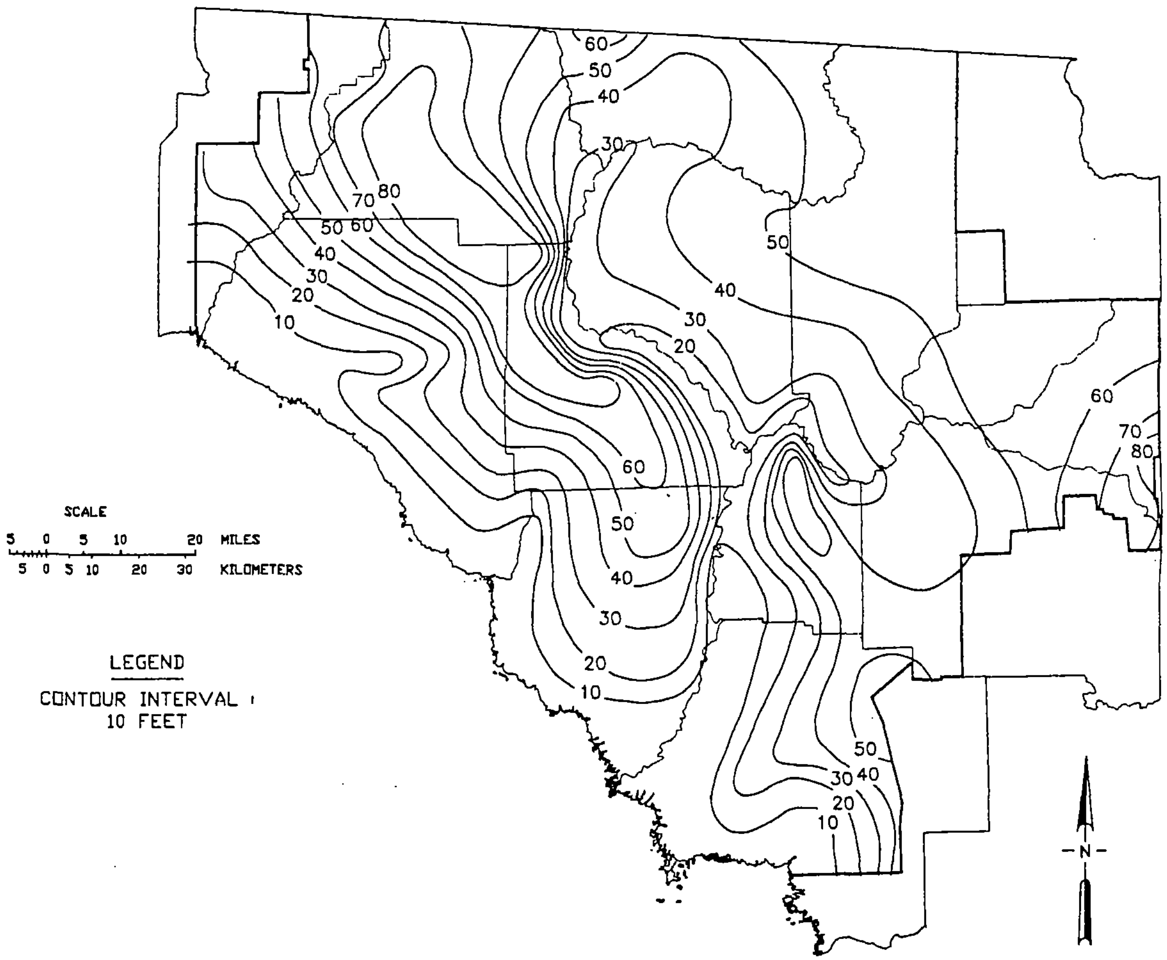


Figure 33. Floridan aquifer system potentiometric surface, SRWMD

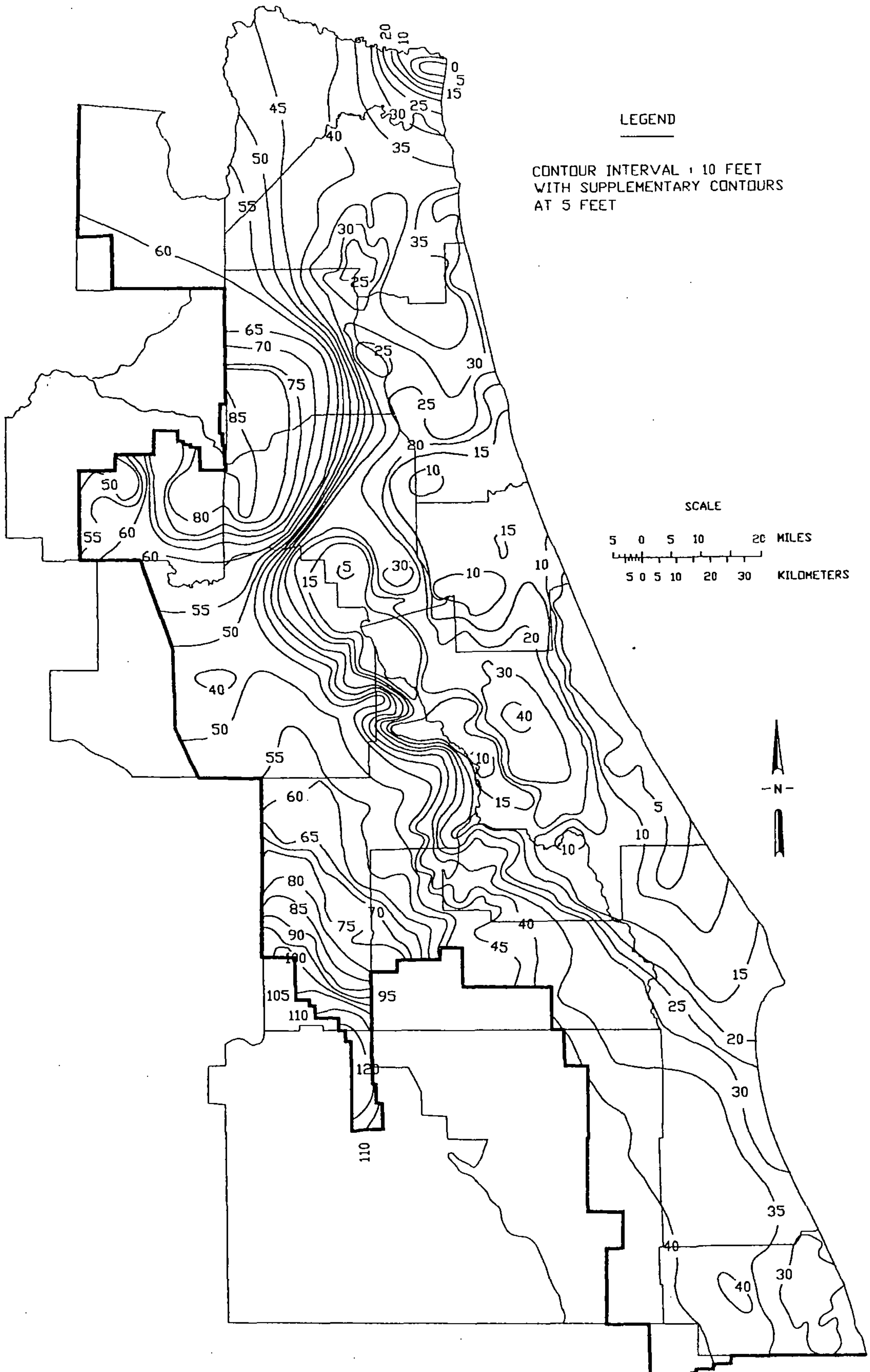


Figure 34. Floridan aquifer system potentiometric surface, SJRWMD

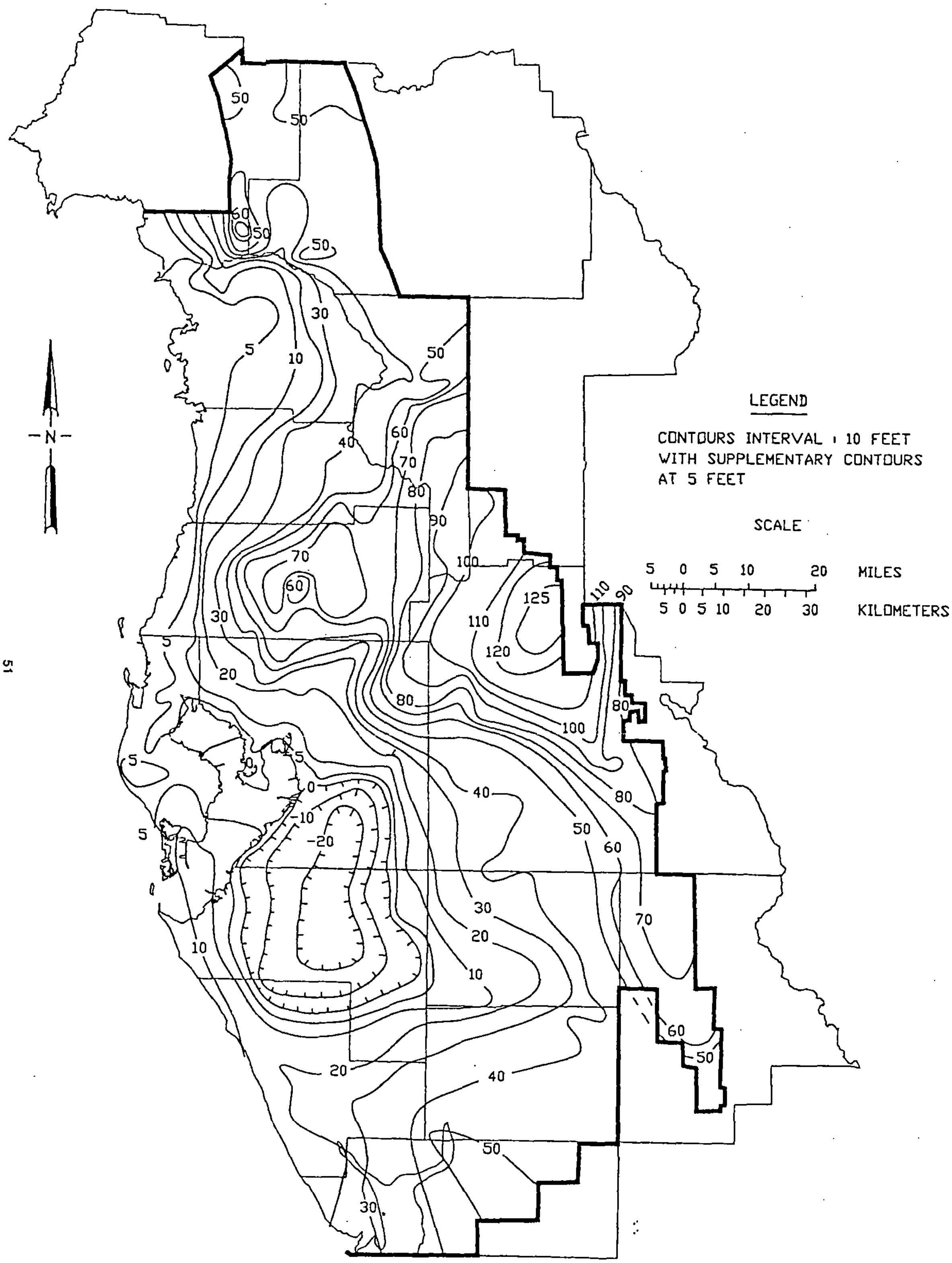


Figure 35. Floridan aquifer system potentiometric surface, SWFWMD (after Barr, 1989)

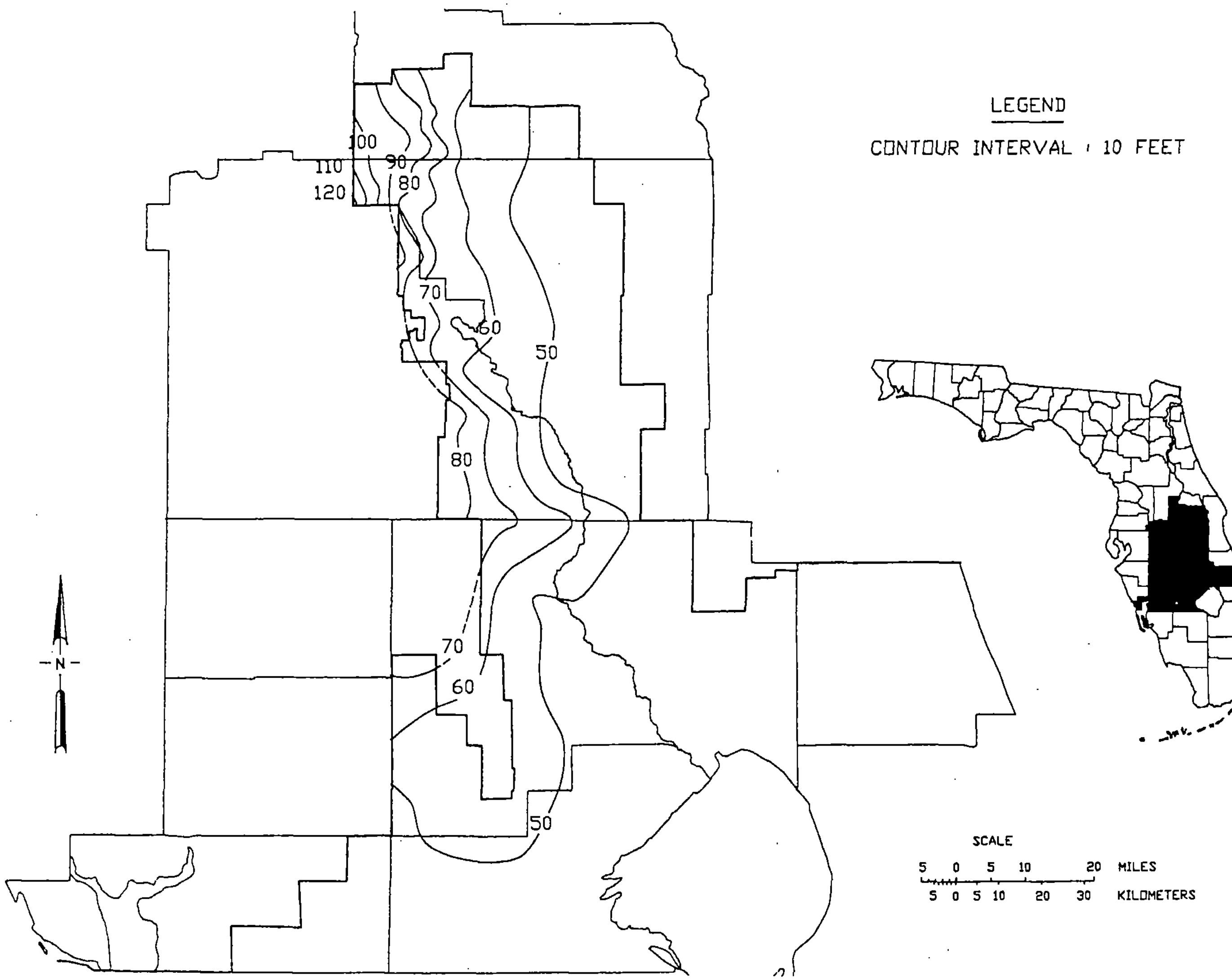


Figure 36. Floridan aquifer system potentiometric surface, SFWMD

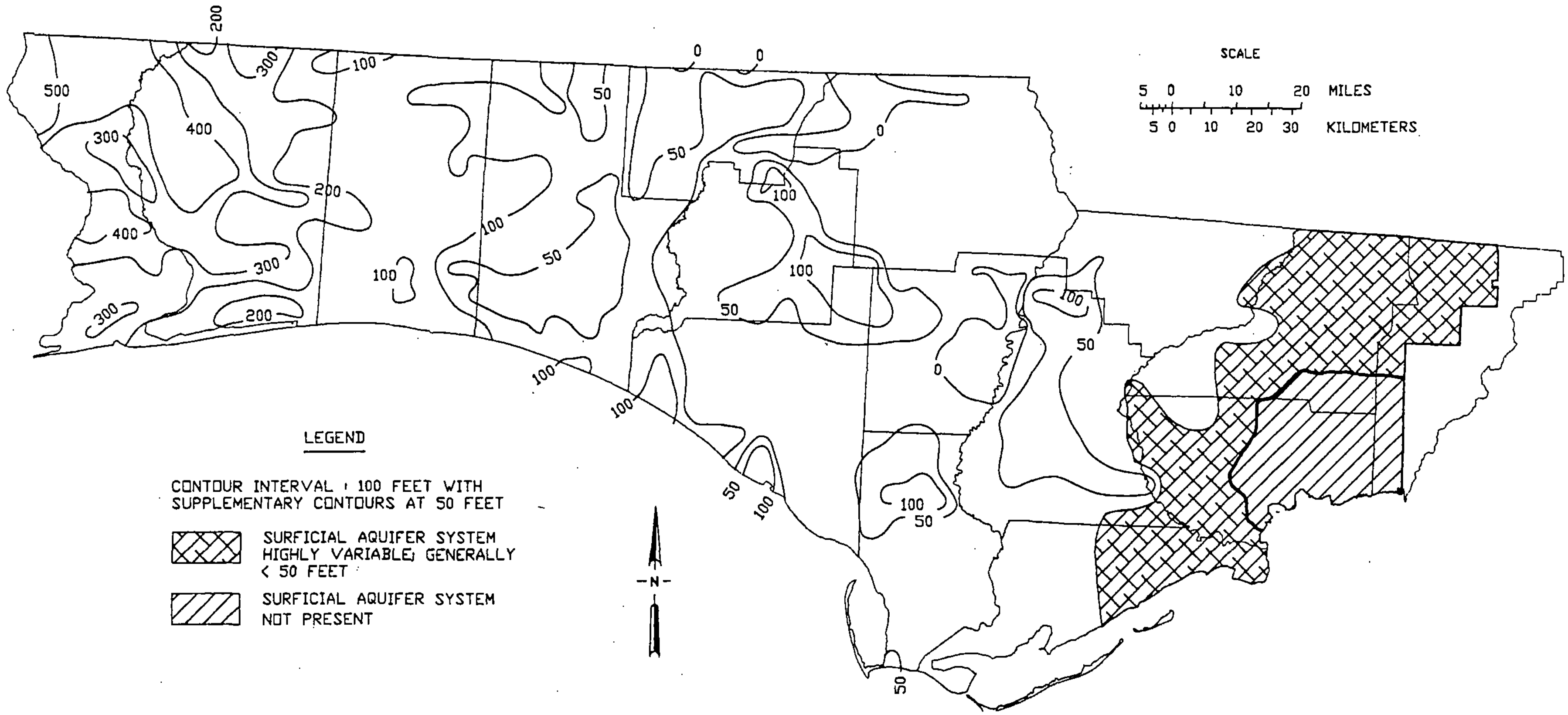


Figure 37. Surficial aquifer system thickness, NWFWMD. This does not represent one continuous aquifer over the extent of the district.

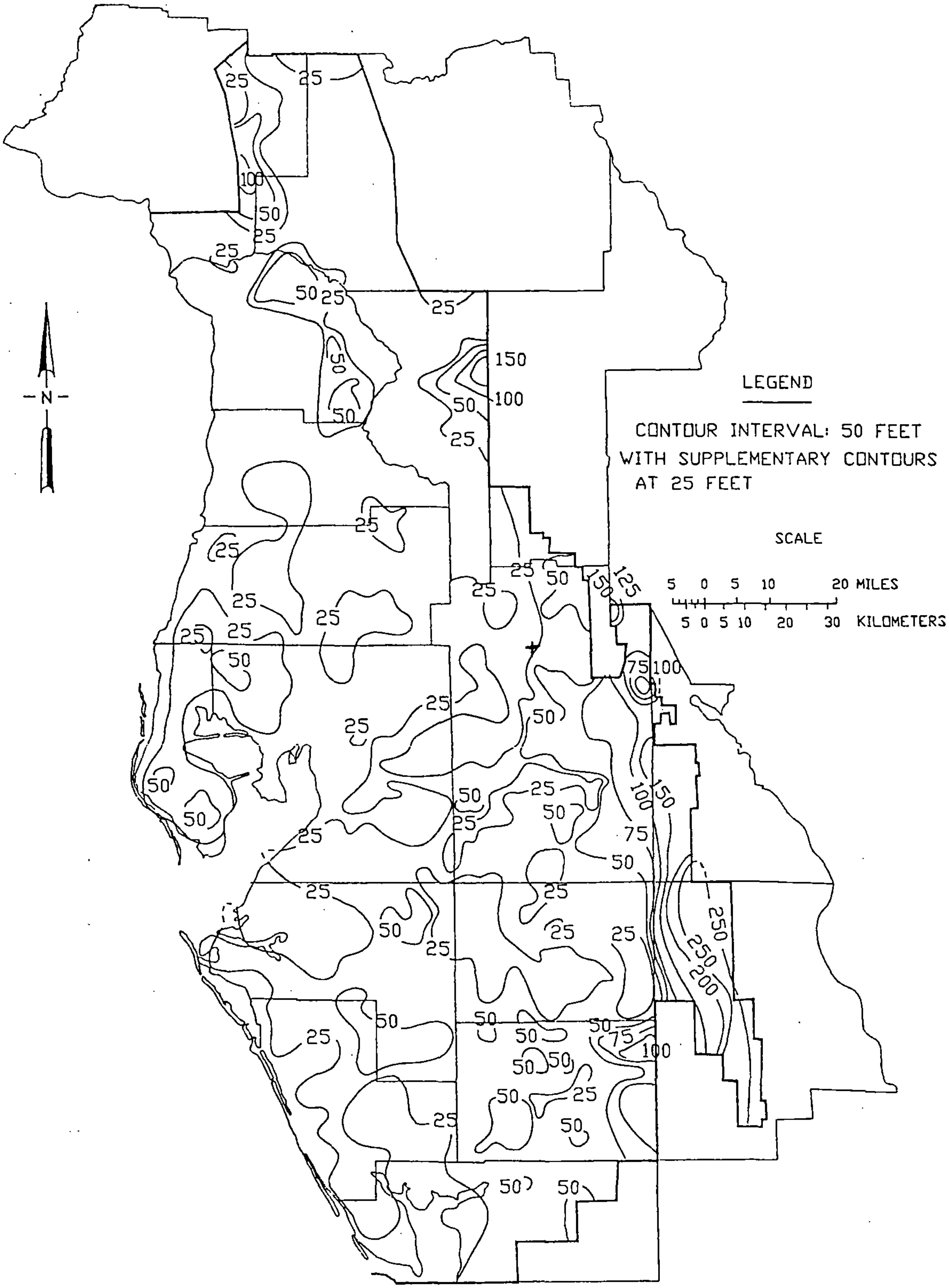


Figure 38. Surficial aquifer system thickness, SWFWMD (after Wolansky and others, 1981)

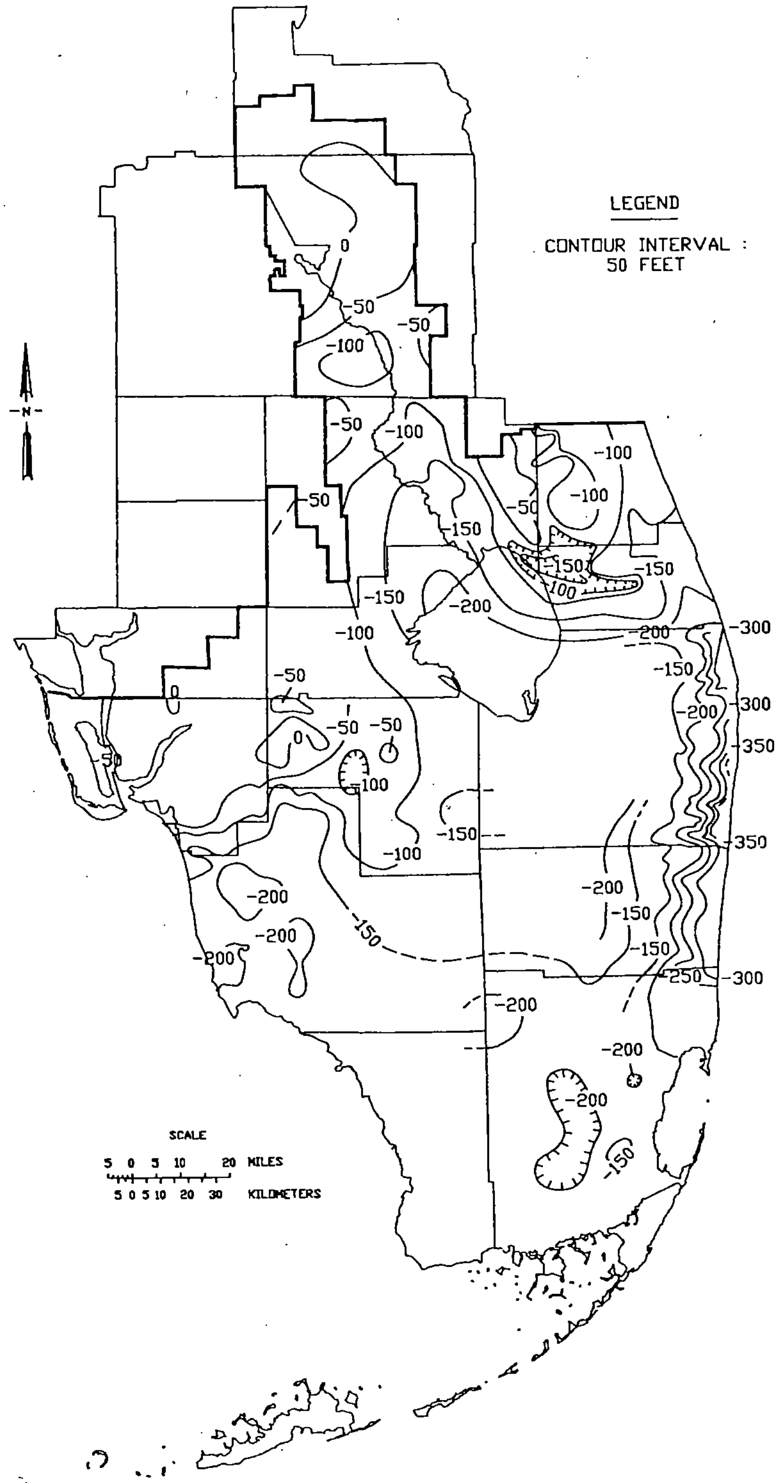


Figure 39. Surficial aquifer system base, SFWMD

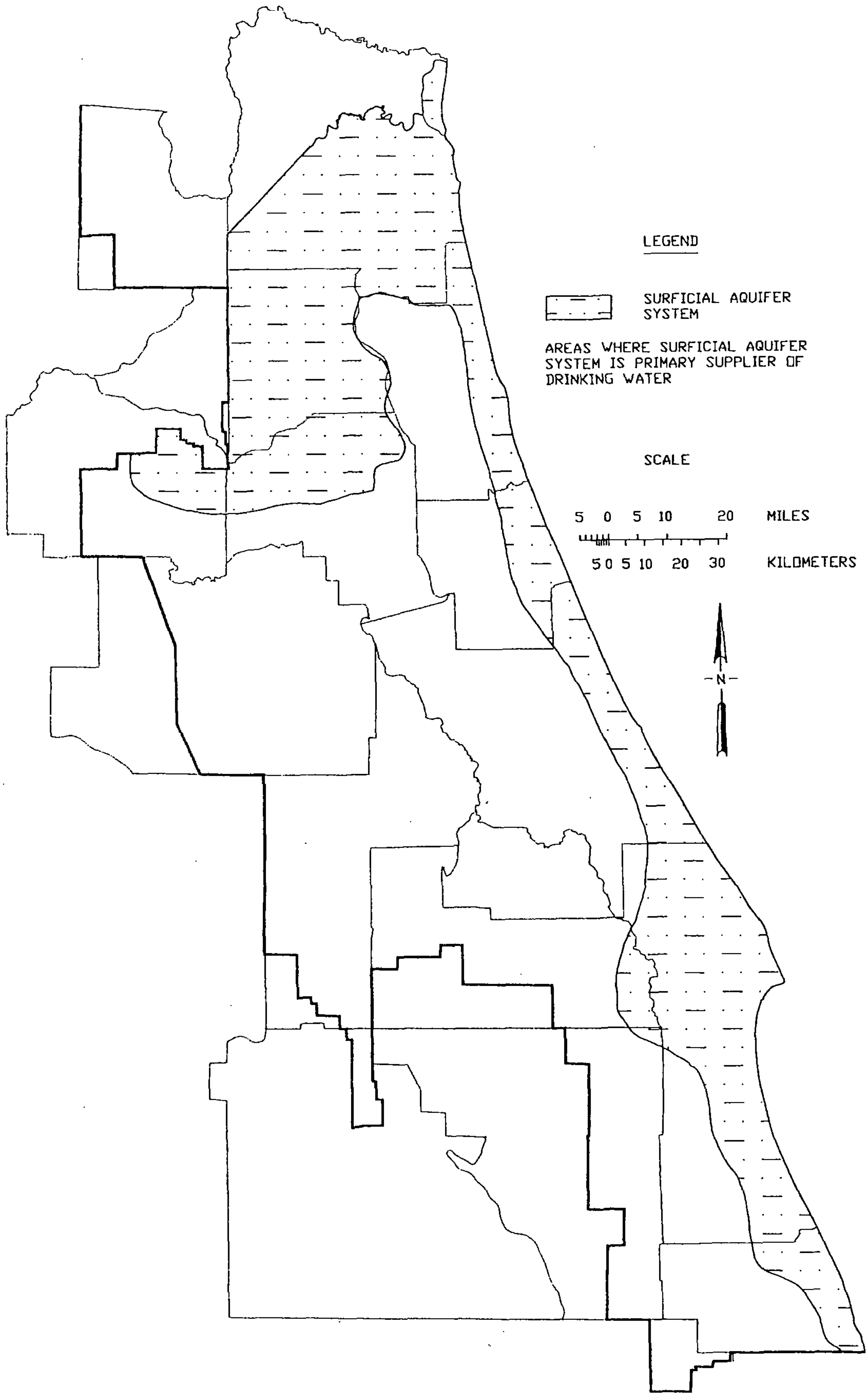


Figure 40. Areas of surficial aquifer system use, SJRWMD

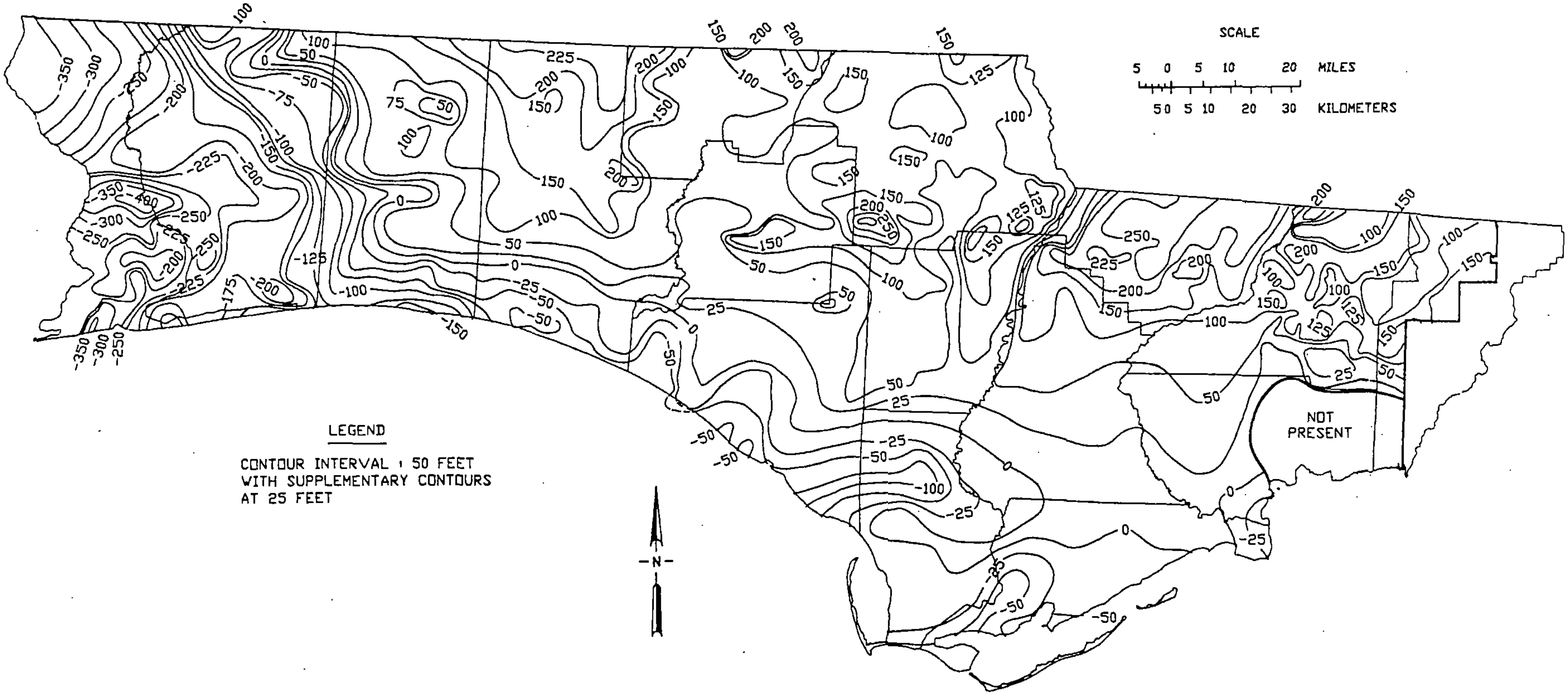


Figure 41. Top of intermediate aquifer system/confining unit, NWFWMD

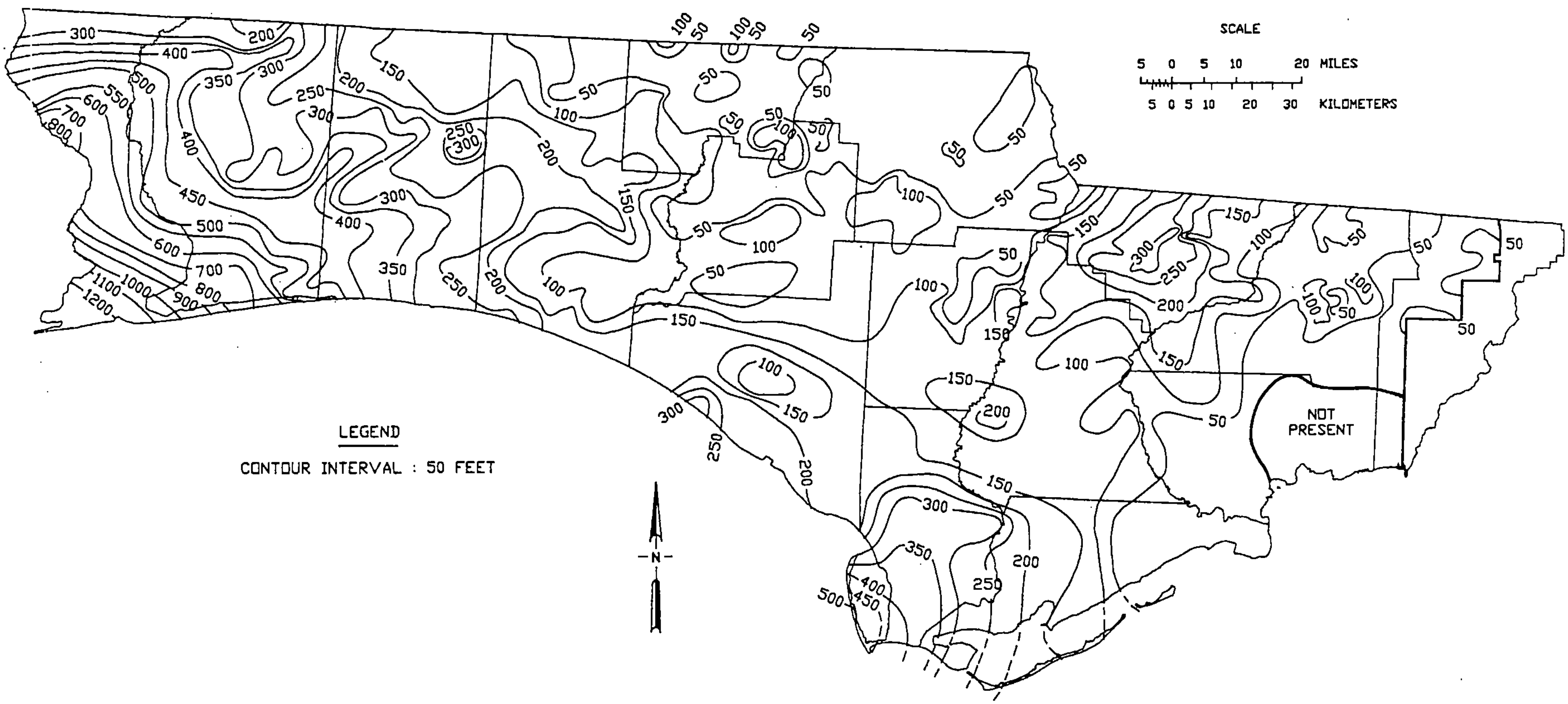


Figure 42. Isopach of the intermediate aquifer system/confining unit, NWFWMD

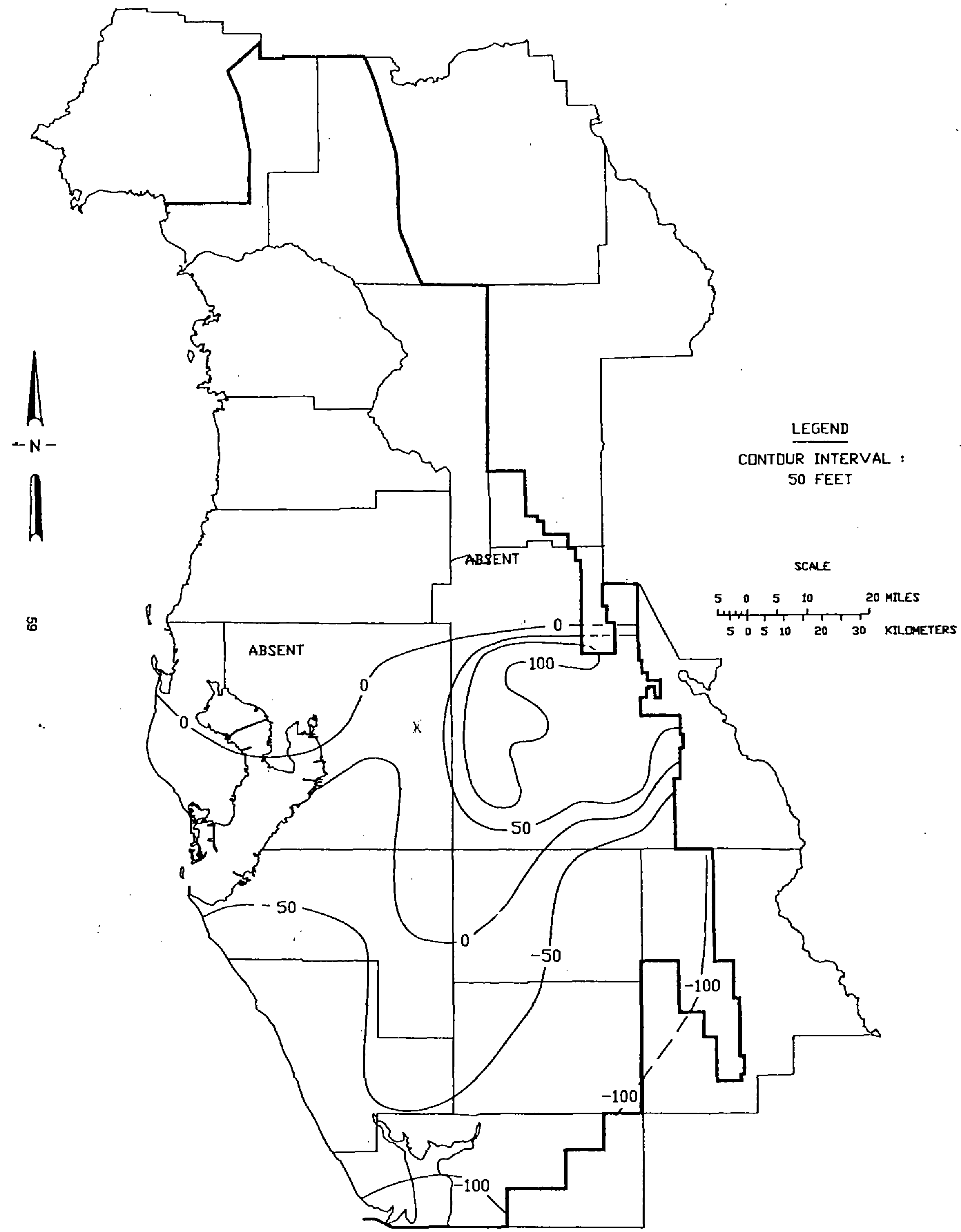


Figure 43. Top of the intermediate aquifer system, SWFWMD (after Corral and Wolansky, 1984)

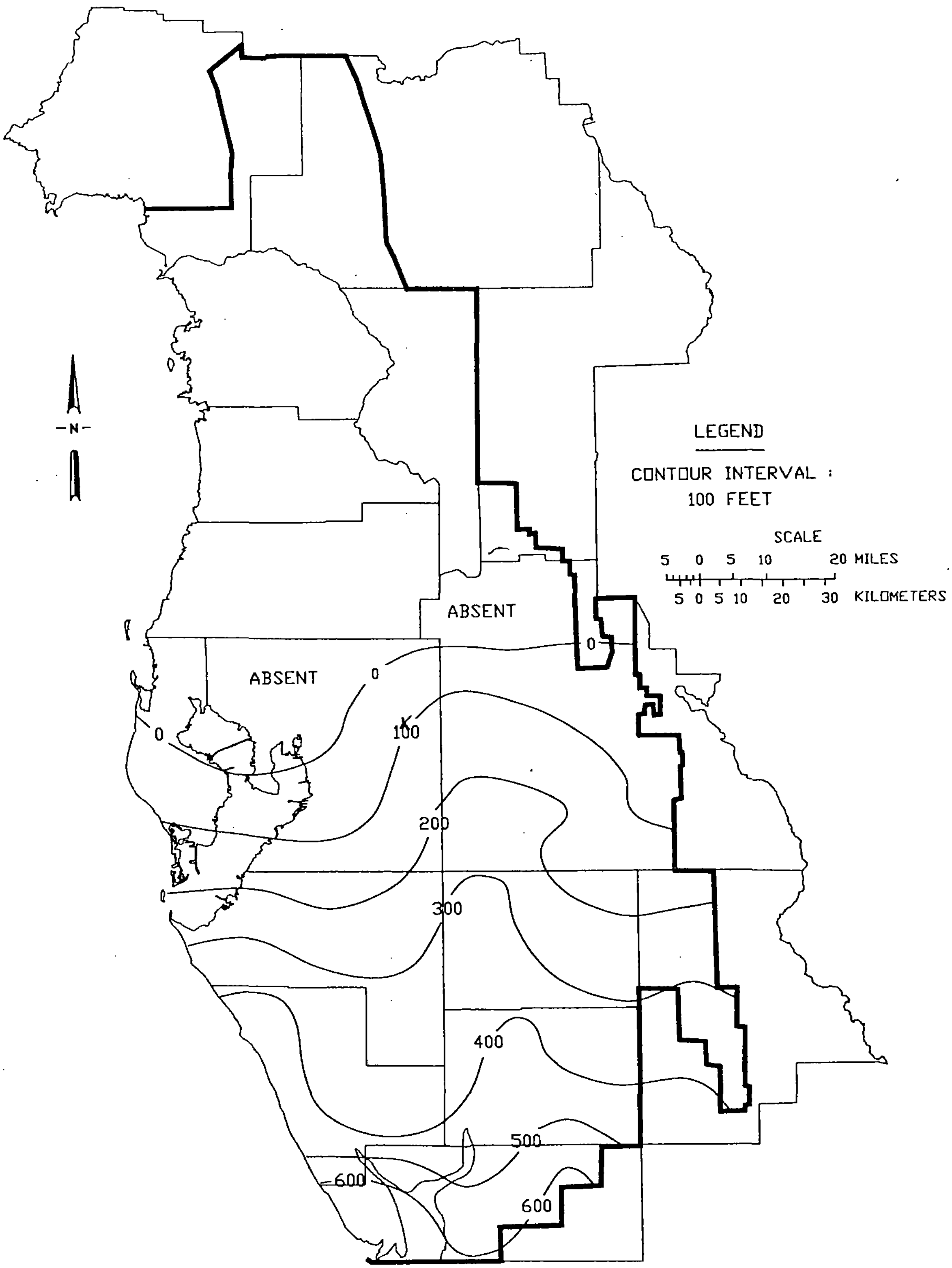


Figure 44. Thickness of the intermediate aquifer system, SWFWMD (after Corral and Wolansky, 1984)

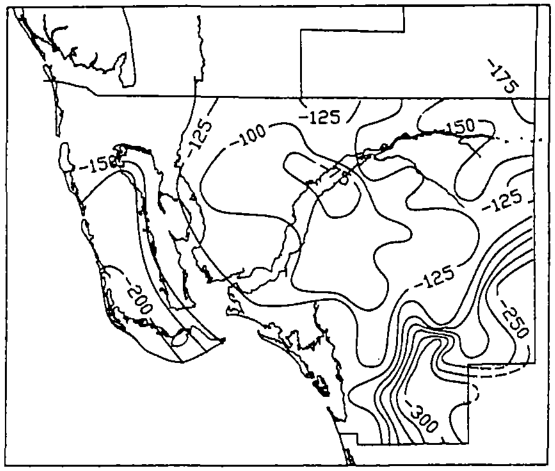


Figure 45. Top of mid-Hawthorn confining zone

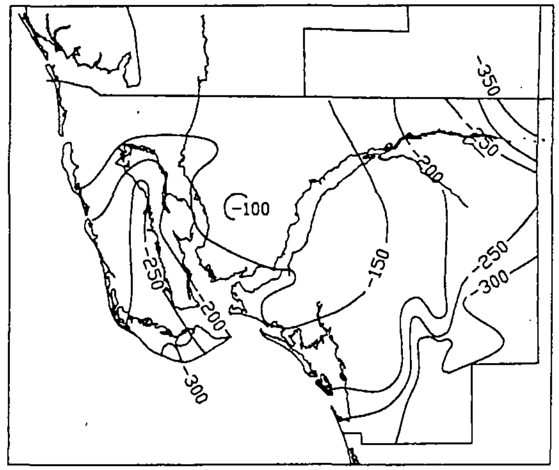


Figure 47. Top of mid-Hawthorn aquifer

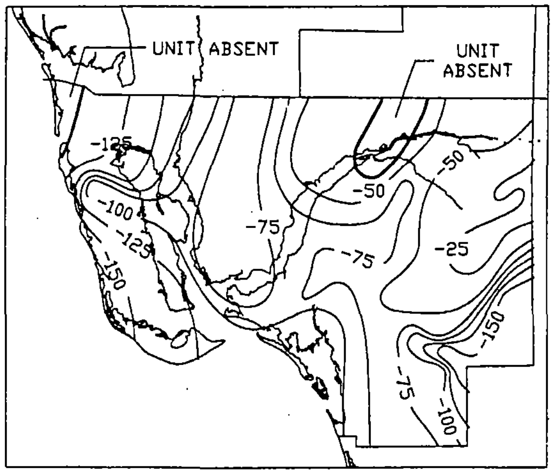
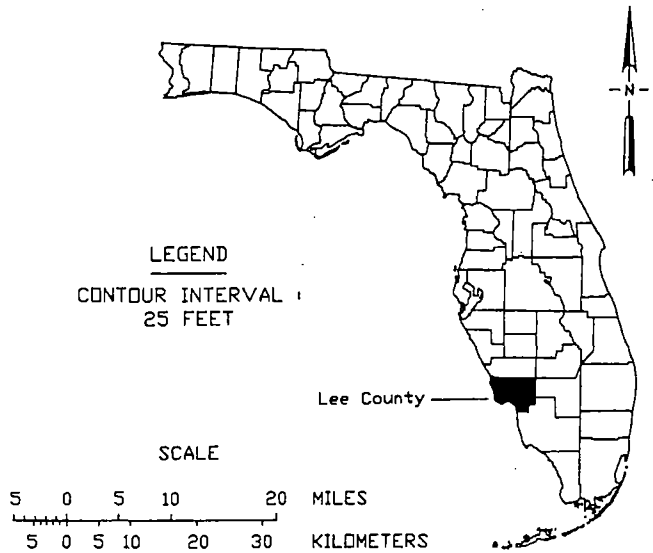
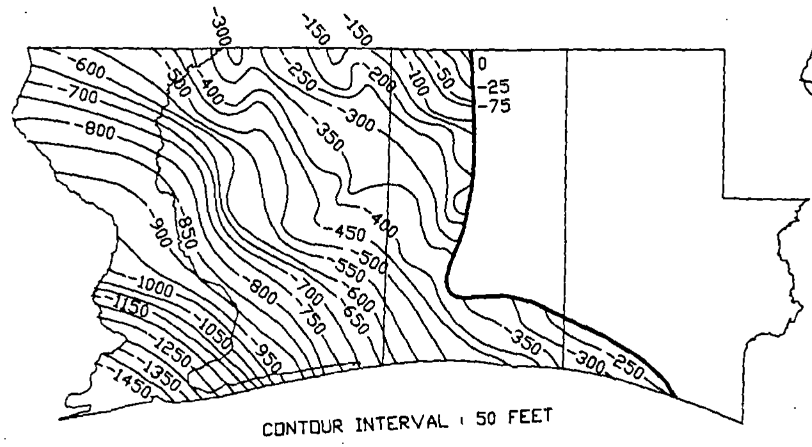
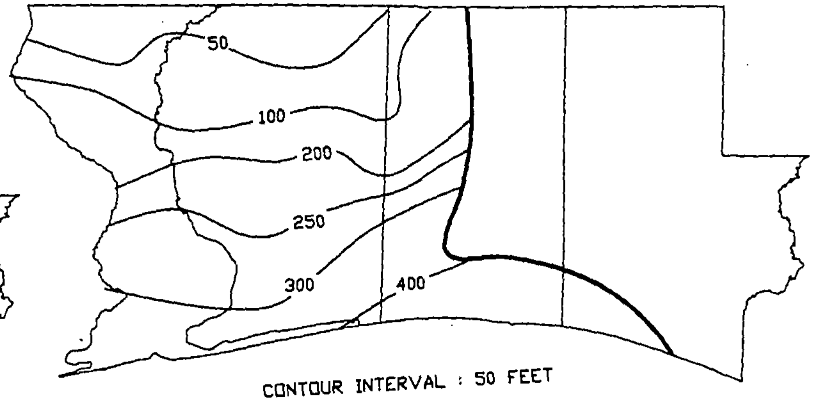


Figure 46. Top of the sandstone aquifer







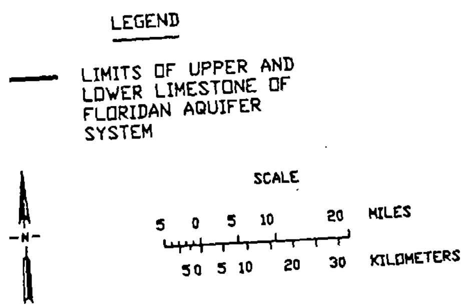
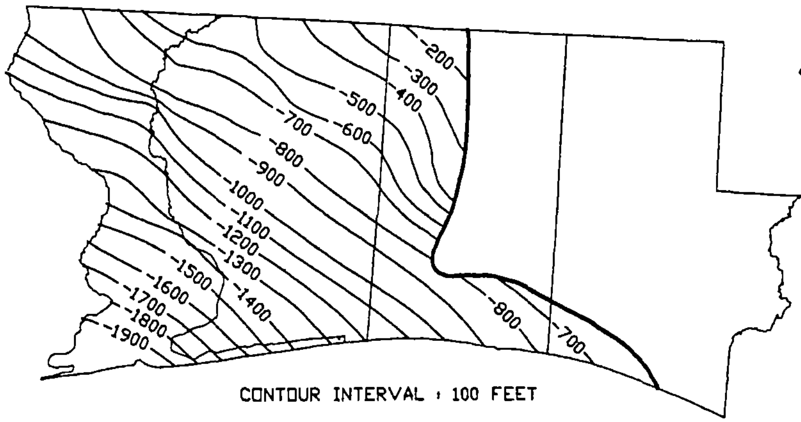
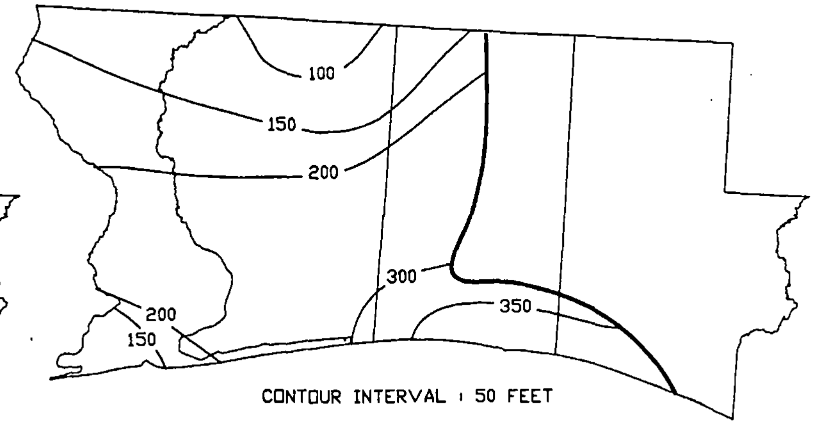


Figure 48. Top of the upper Floridan aquifer system, NWFWMD

Figure 49. Thickness of the upper Floridan aquifer system, NWFWMD





LEGEND

LIMITS OF UPPER AND LOWER LIMESTONE OF FLORIDAN AQUIFER SYSTEM

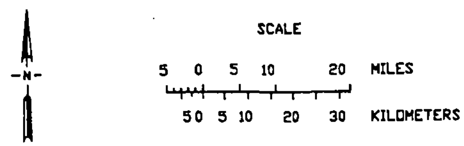
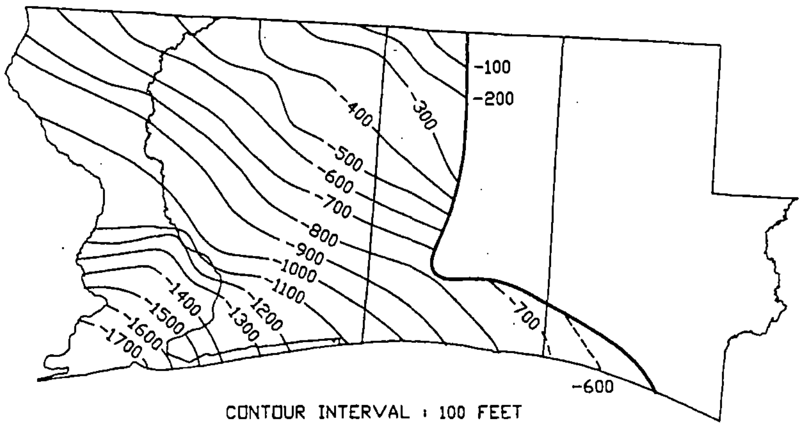
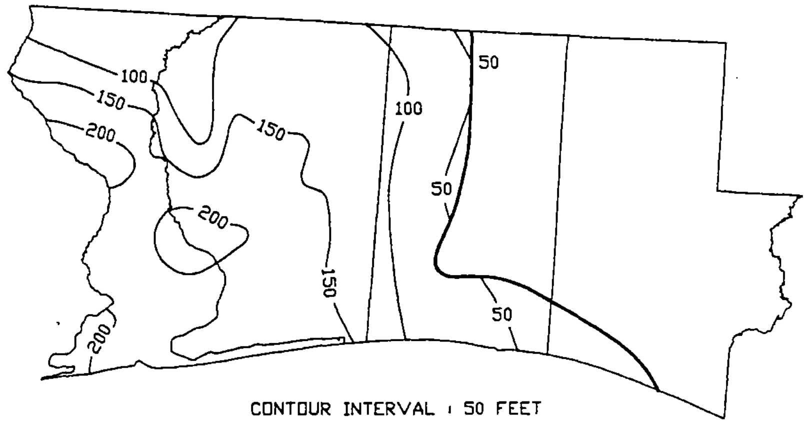


Figure 50. Top of the lower Floridan aquifer system, NWFWMD

Figure 51. Thickness of the lower Floridan aquifer system, NWFWMD





LEGEND

EASTERN EXTENT OF THE BUCATUNNA CLAY CONFINING UNIT

N

SCALE

5 0 5 10 20 MILES

5 0 5 10 20 30 KILOMETERS

Figure 52. Top of the Bucatunna Clay, NWFWMD

Figure 53. Thickness of the Bucatunna Clay, NWFWMD

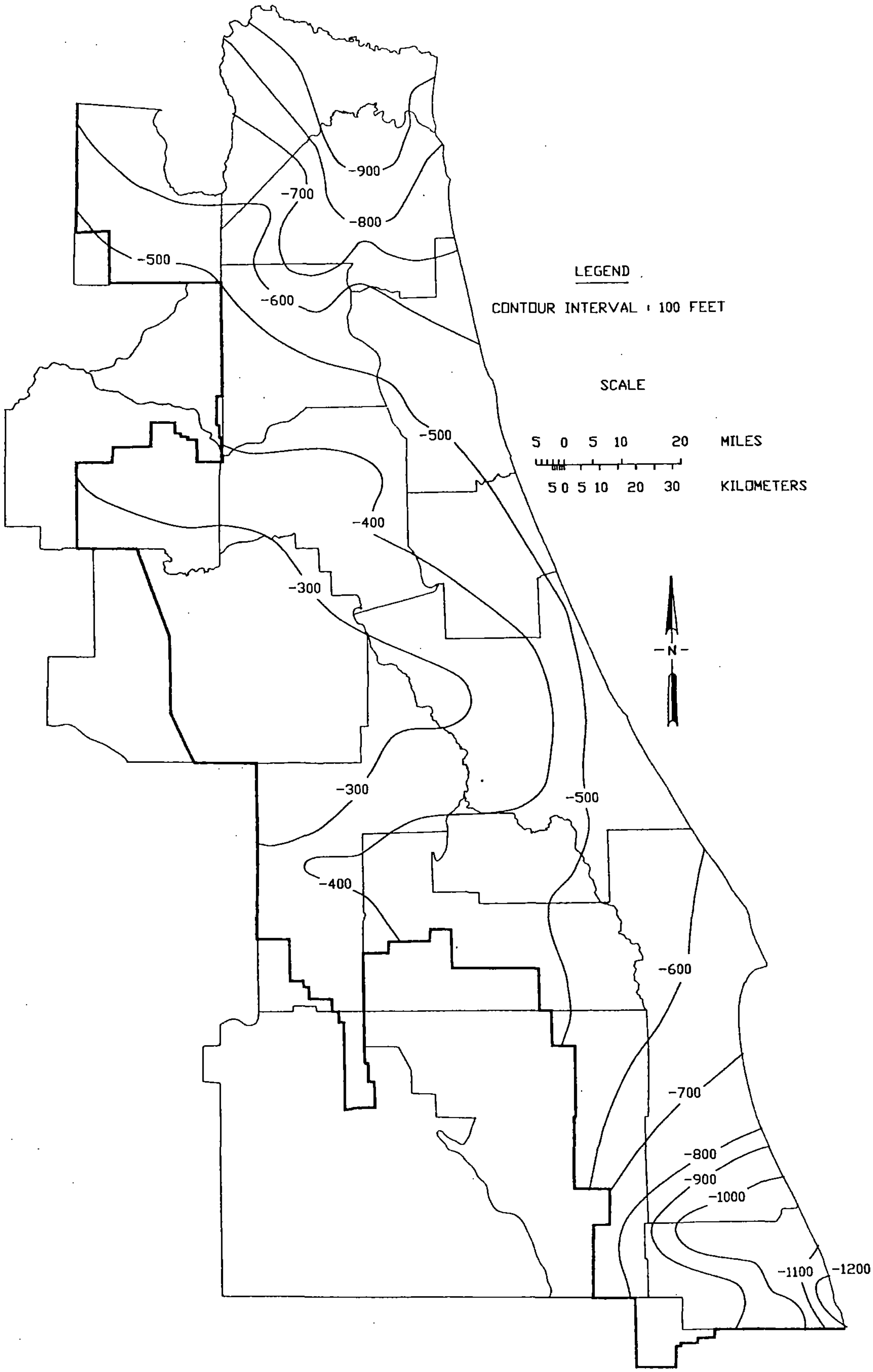


Figure 54. Top of the lower Floridan aquifer system, SJRWMD

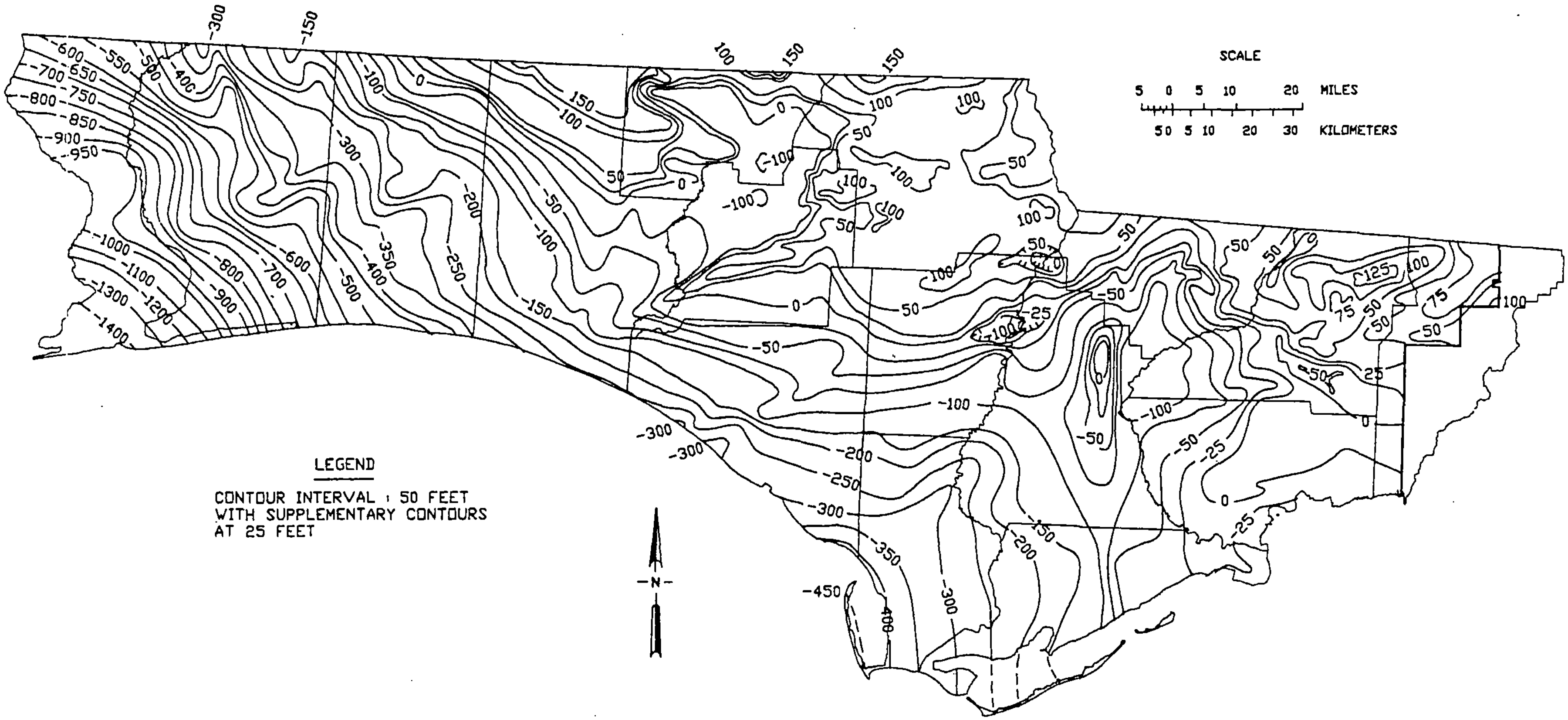


Figure 55. Top of the Floridan aquifer system, NWFWMD

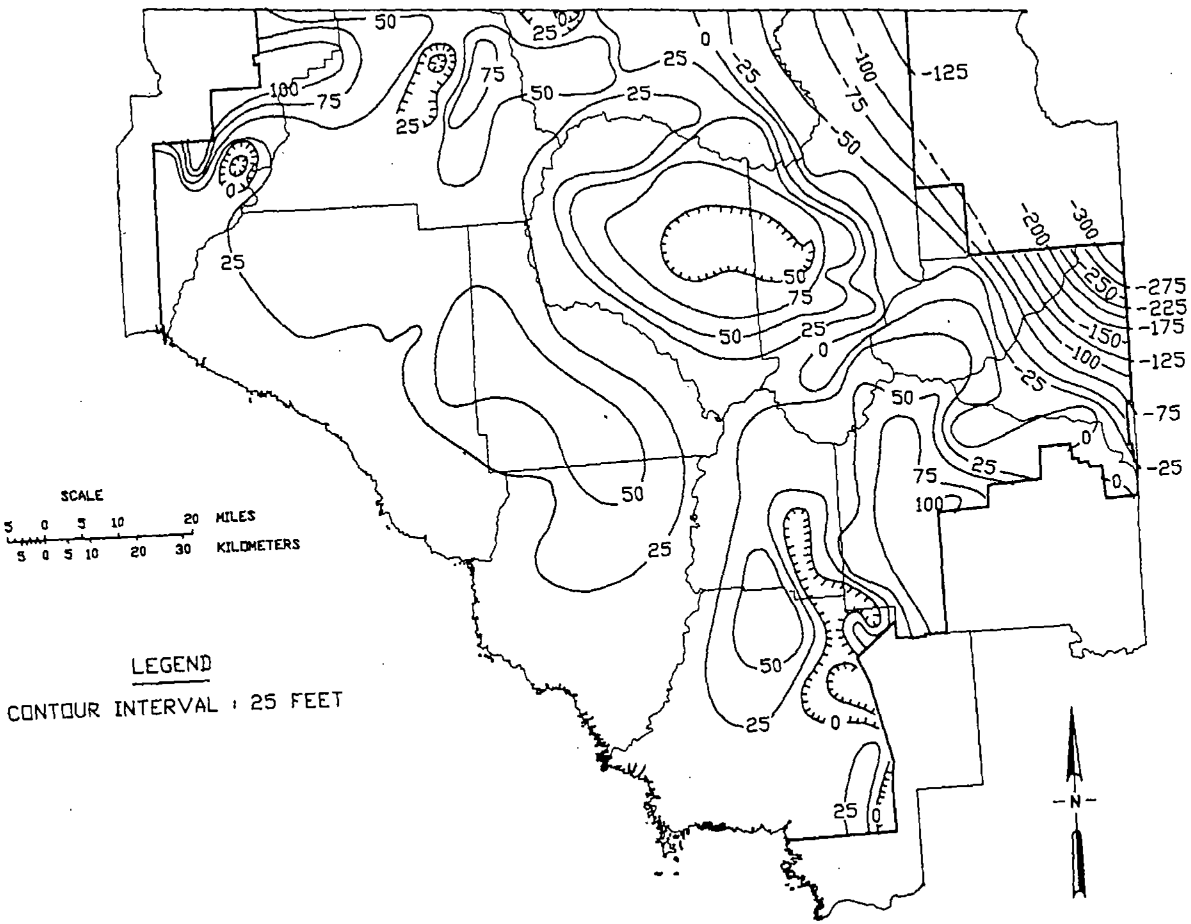


Figure 56. Top of the Floridan aquifer system, SRWMD

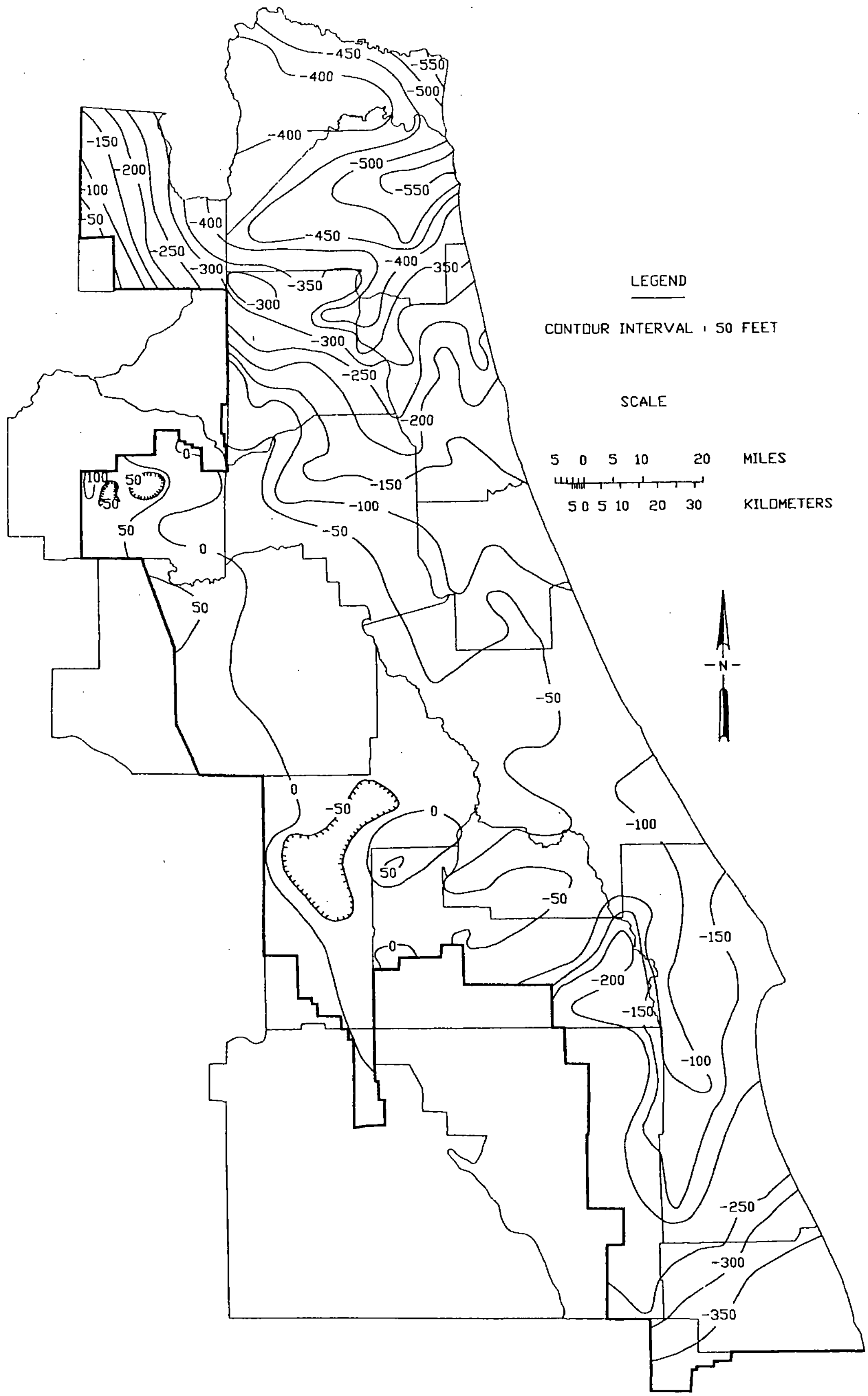


Figure 57. Top of the Floridan aquifer system, SJRWMD

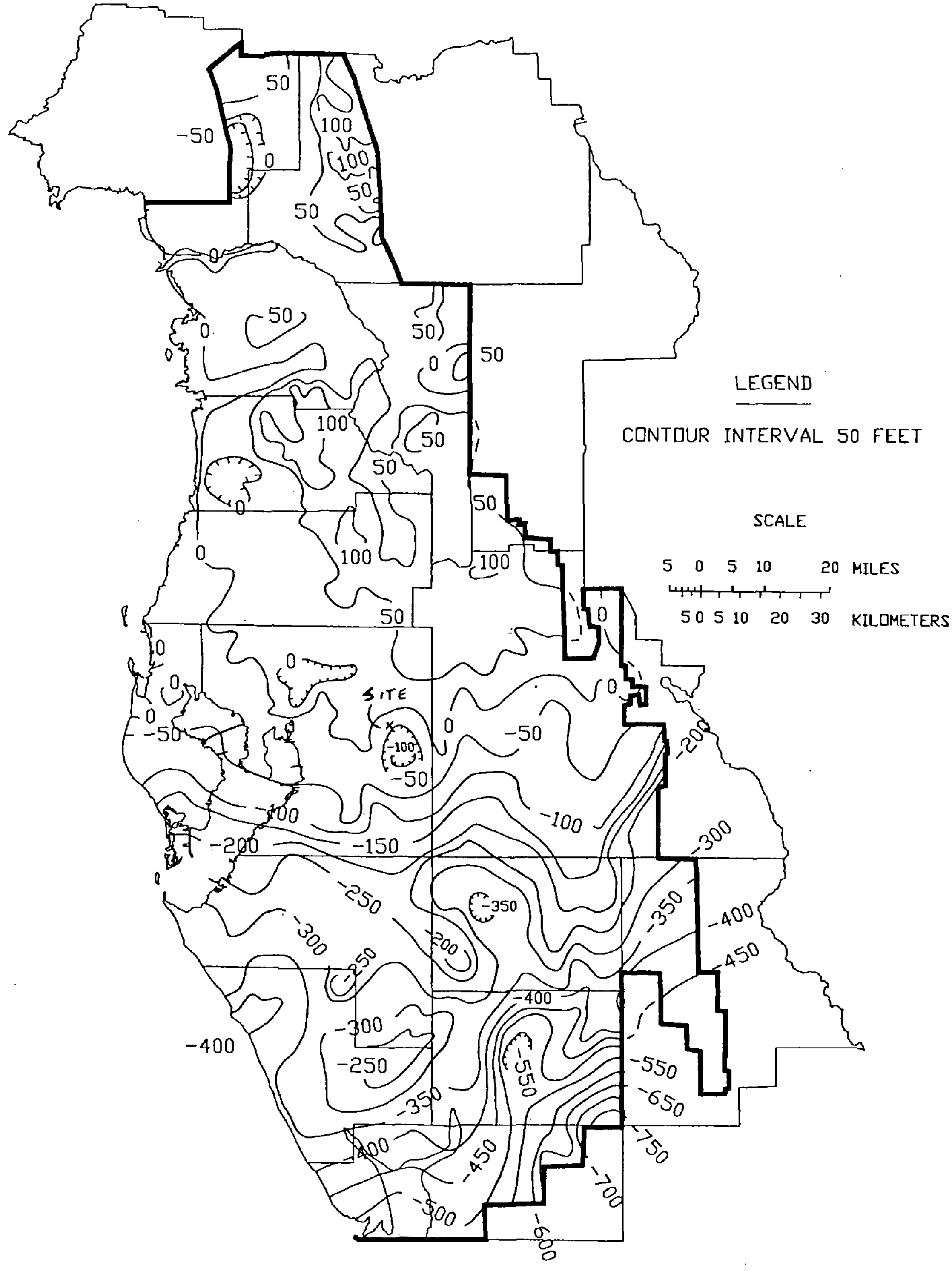


Figure 58. Top of the Floridan aquifer system, SWFWMD

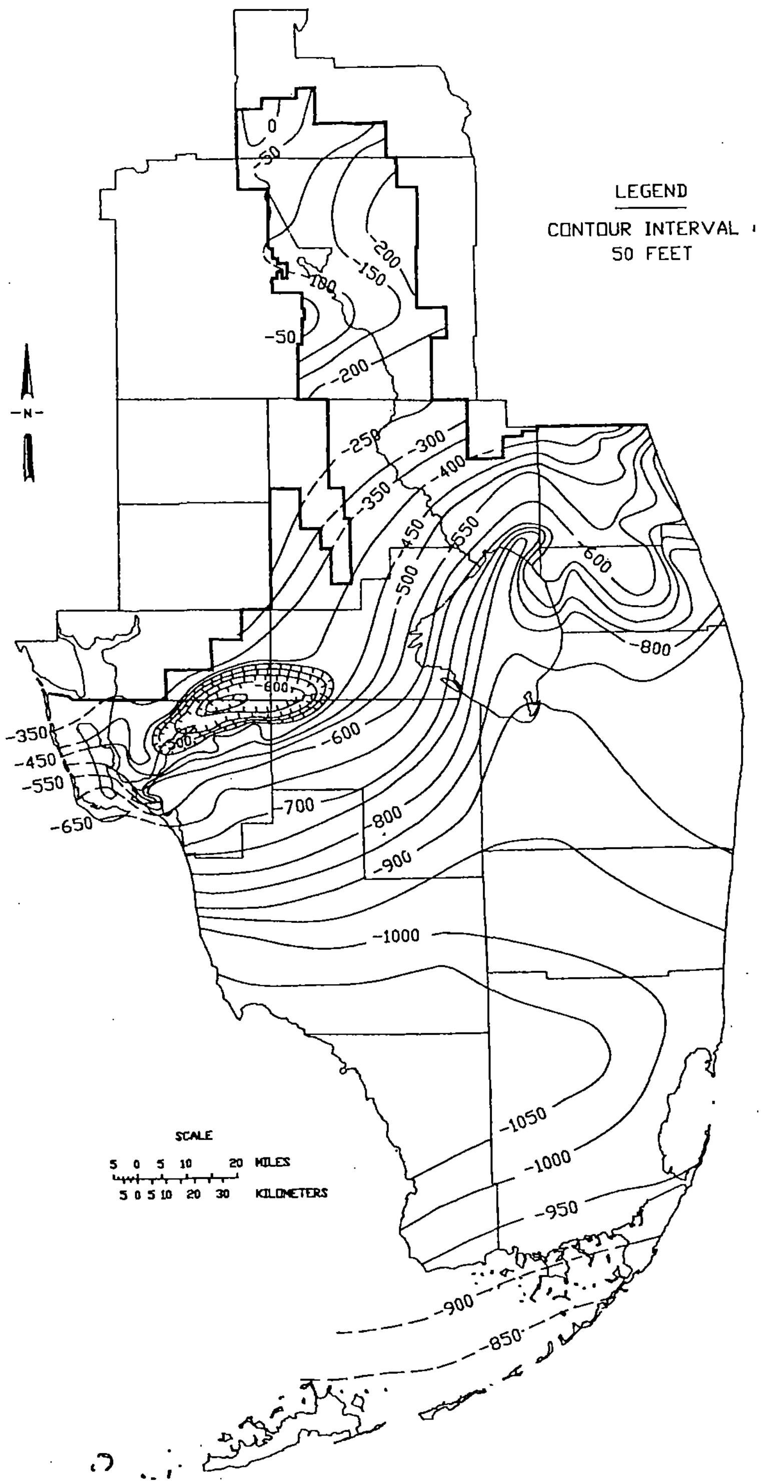


Figure 59. Top of the Floridan aquifer system, SFWMD

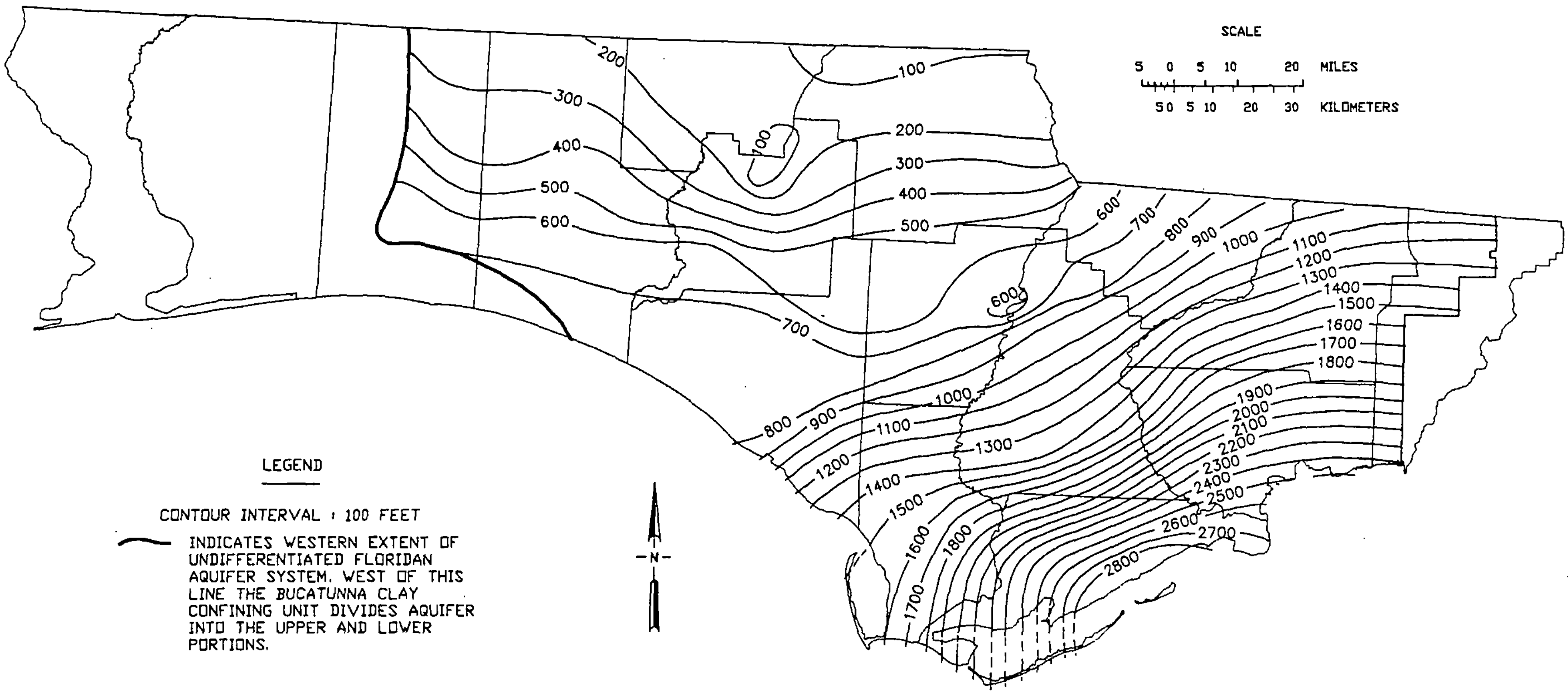


Figure 60. Thickness of the Floridan aquifer system, NWFWMD

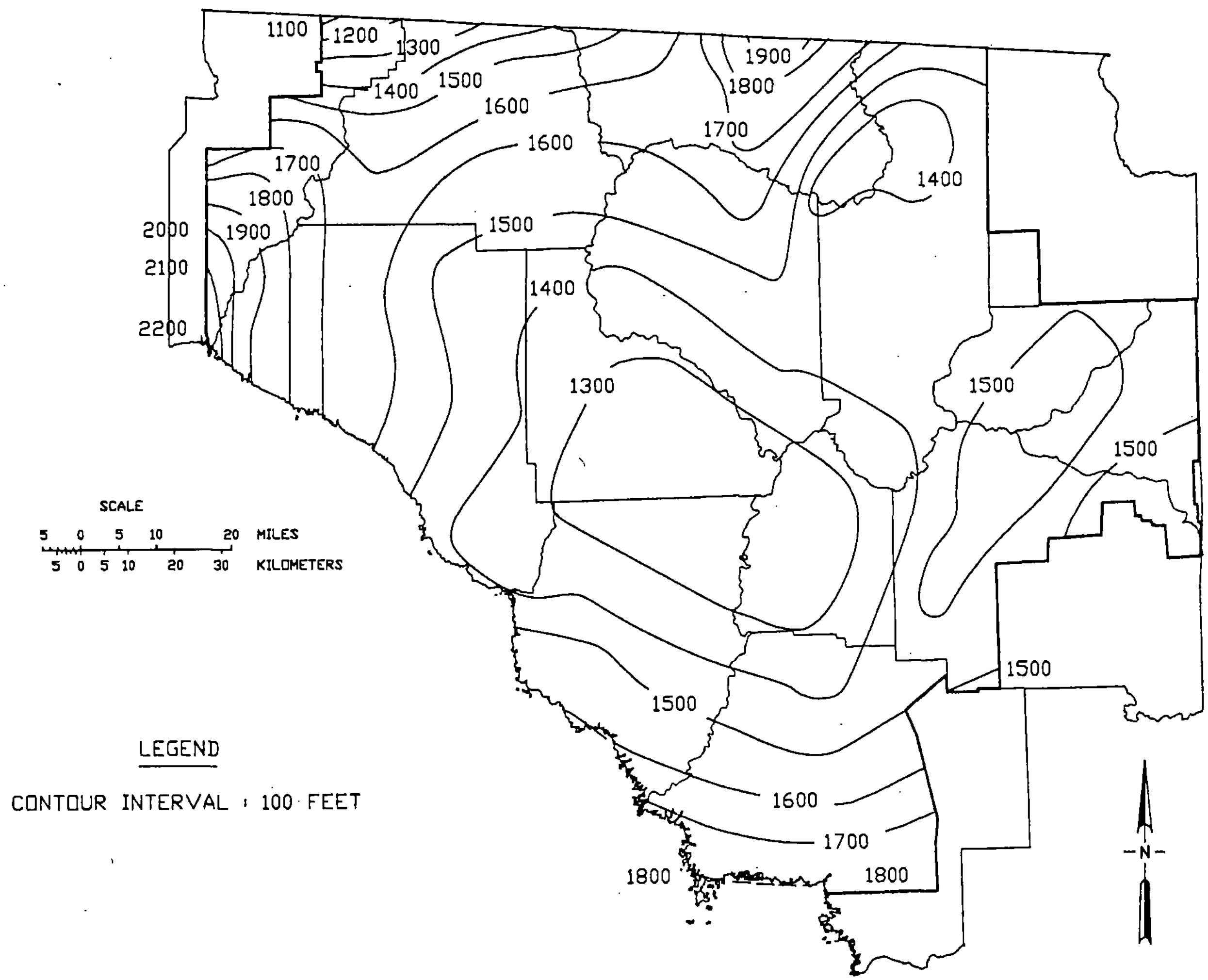


Figure 61. Thickness of the Floridan aquifer system, SRWMD (after Miller, 1986)

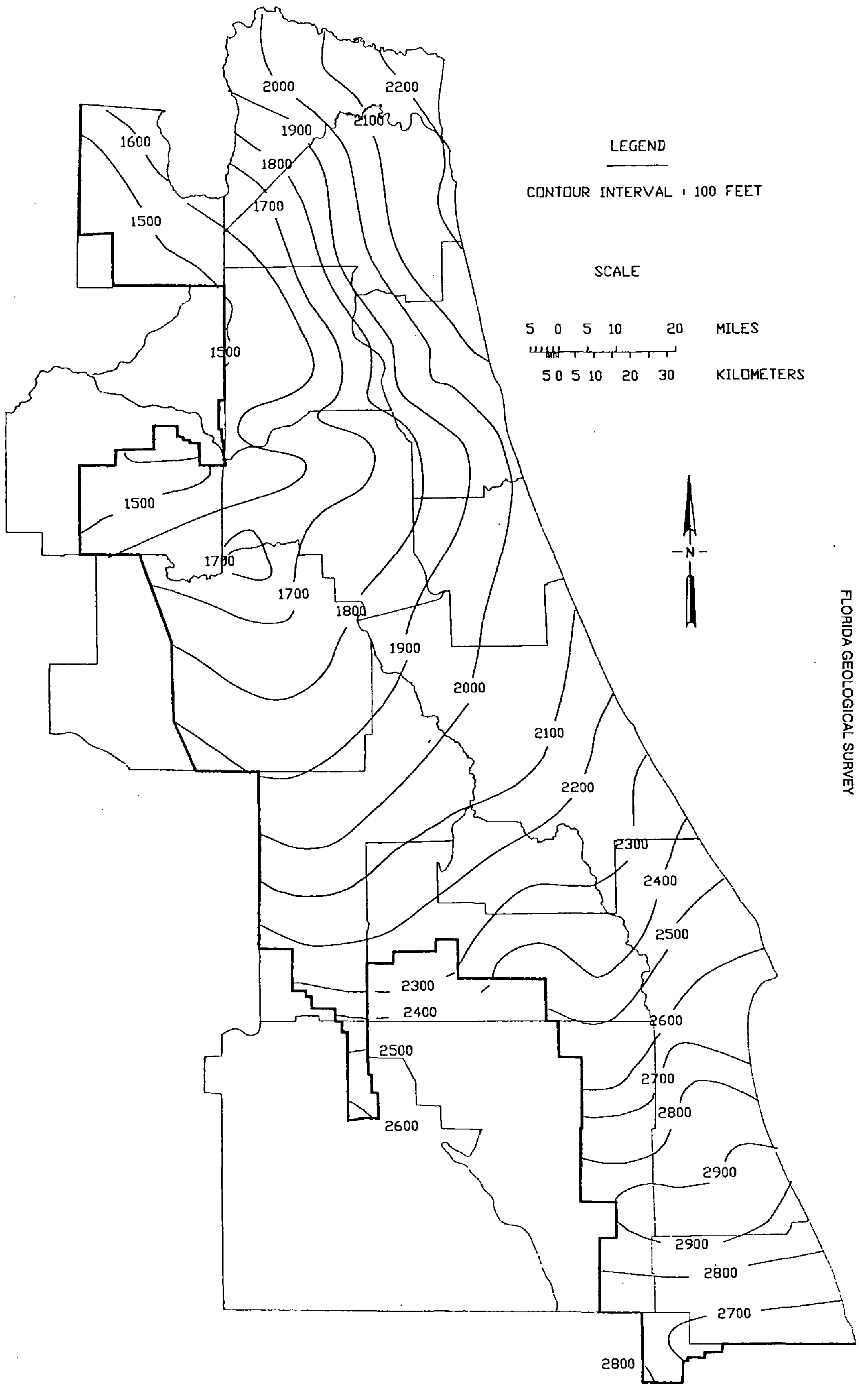


Figure 62. Thickness of the Floridan aquifer system, SJRWMD

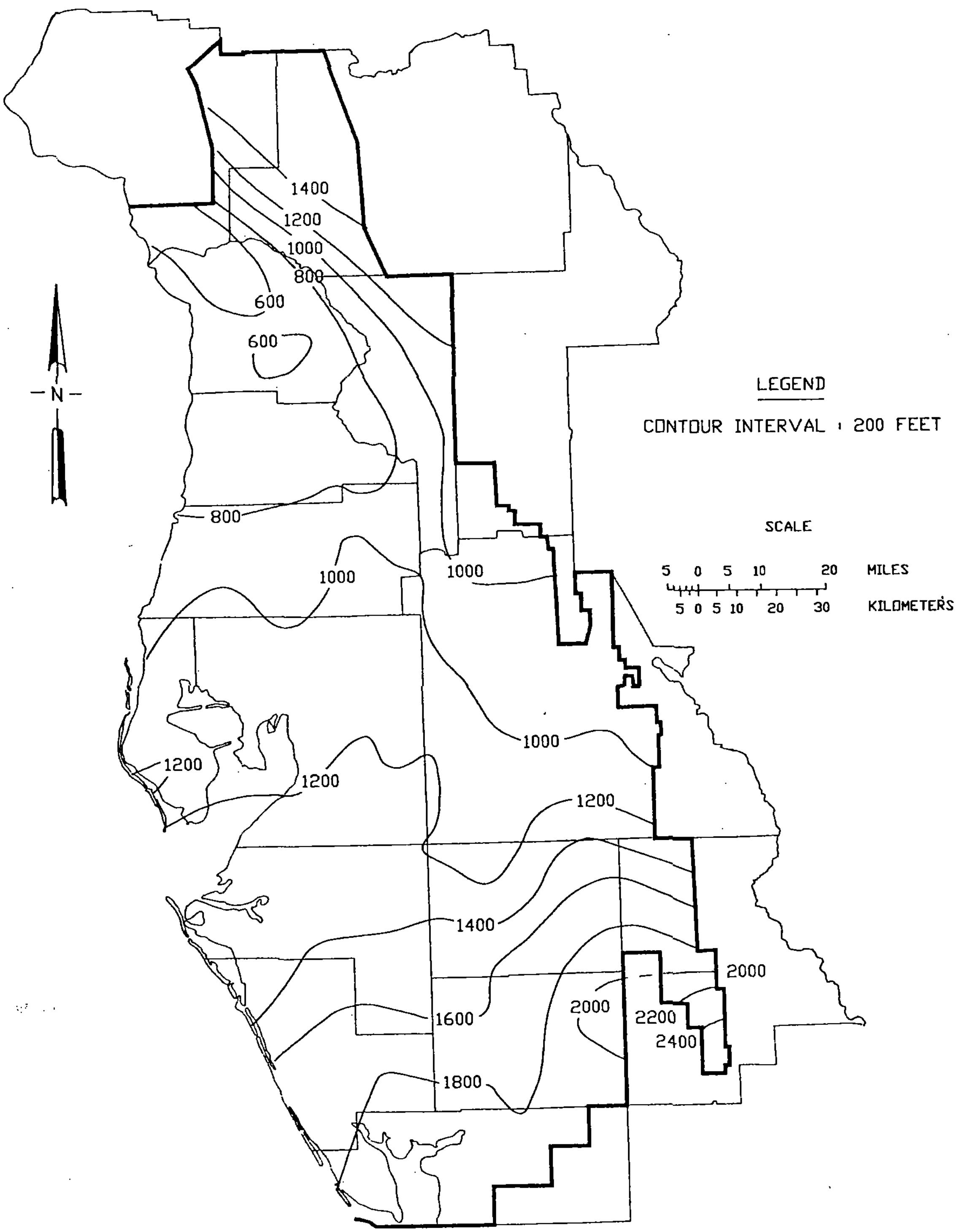


Figure 63. Thickness of the Floridan aquifer system, SWFWMD (after Wolansky and Garbode, 1981)

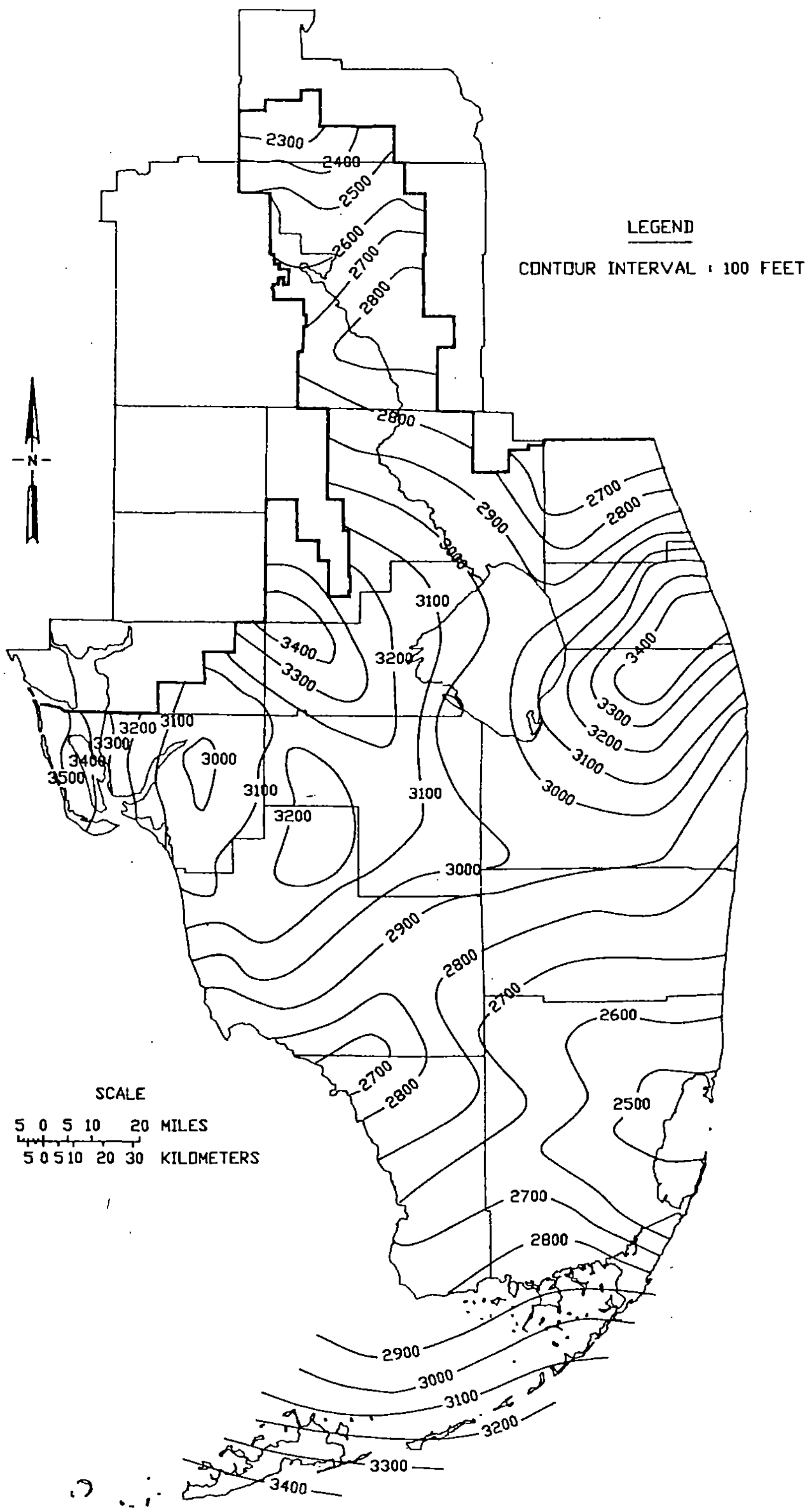


Figure 64. Thickness of the Floridan aquifer system, SFWMD (after Miller, 1986)

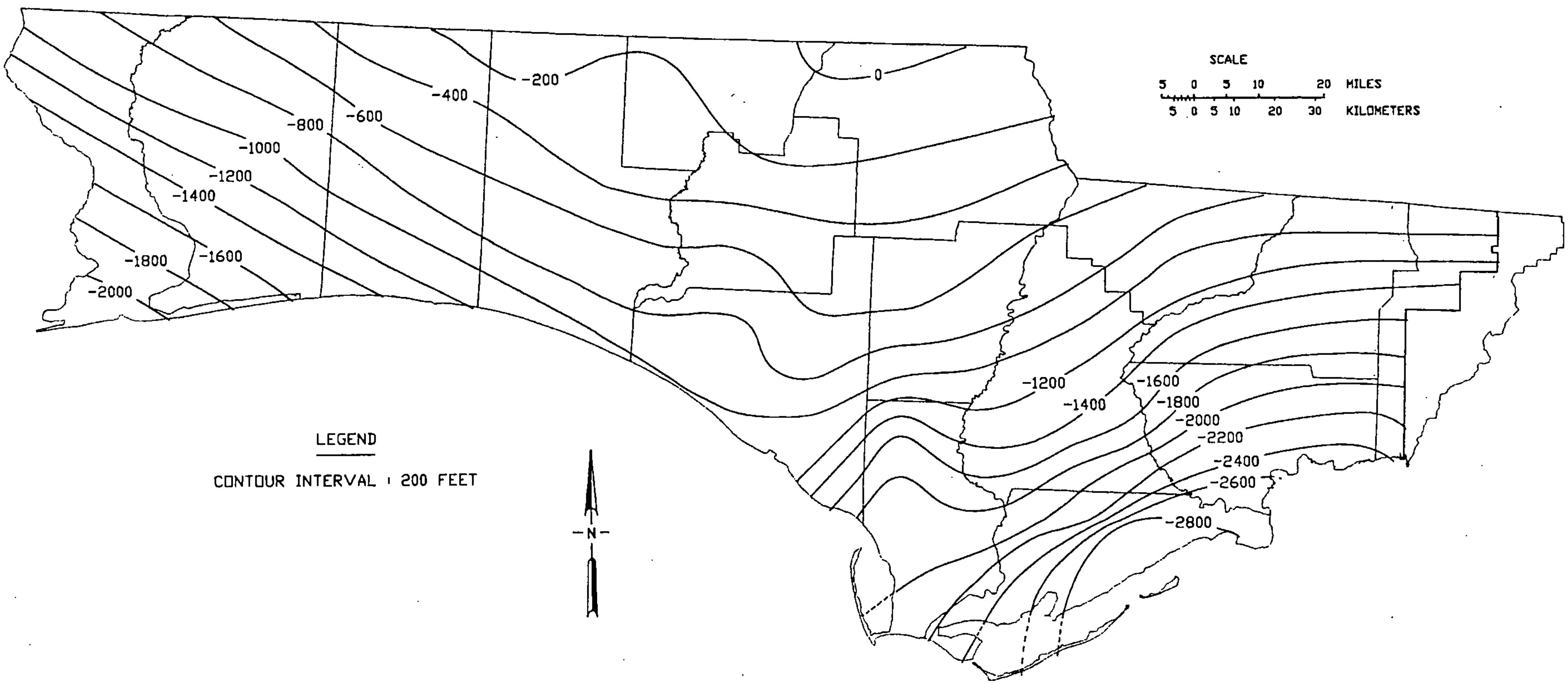


Figure 65. Base of the Floridan aquifer system, NWFWMD

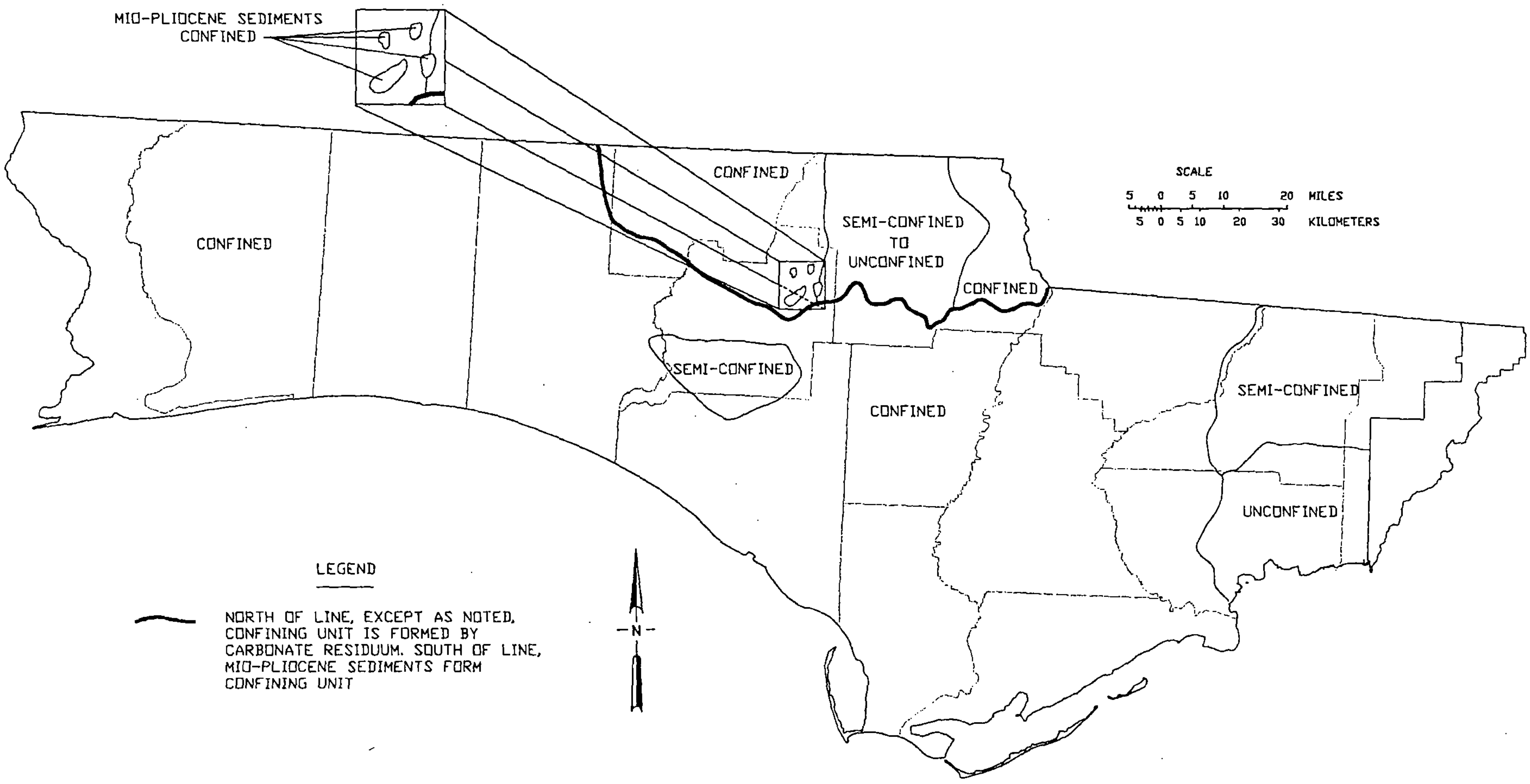


Figure 66. Confinement of the Floridan aquifer system, NWFWMD

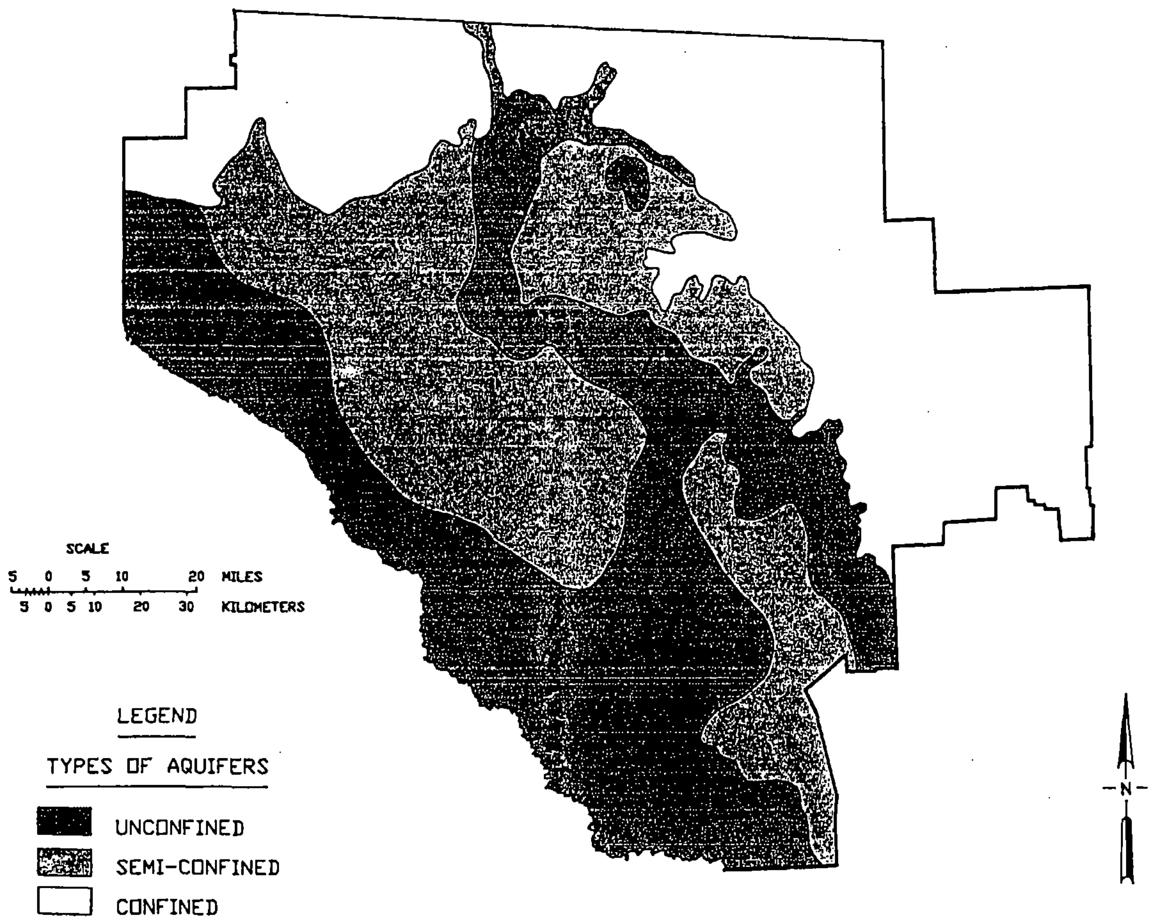


Figure 67. Confinement of the Floridan aquifer system, SRWMD

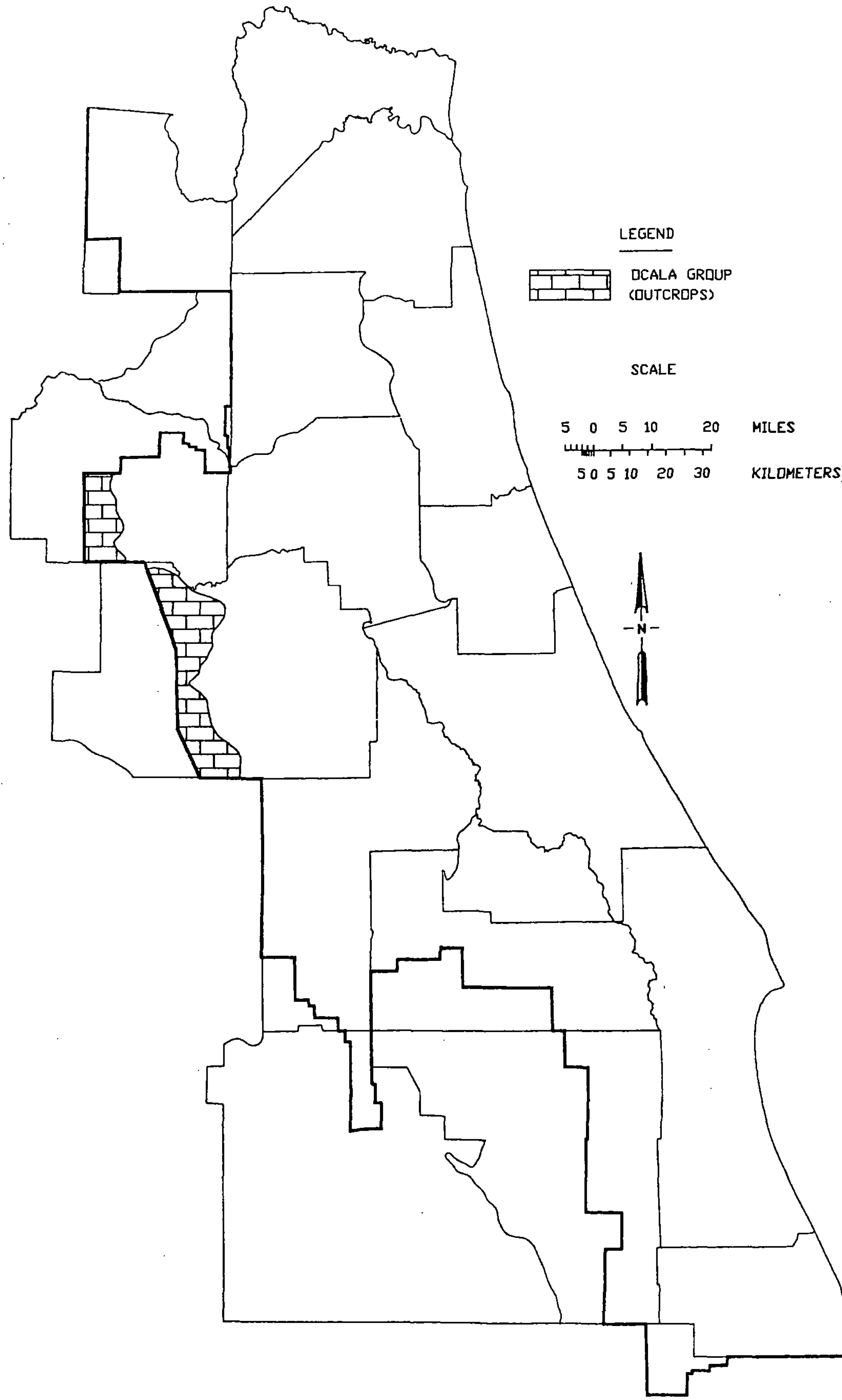


Figure 68. Areas of unconfined Floridan aquifer system, SJRWMD

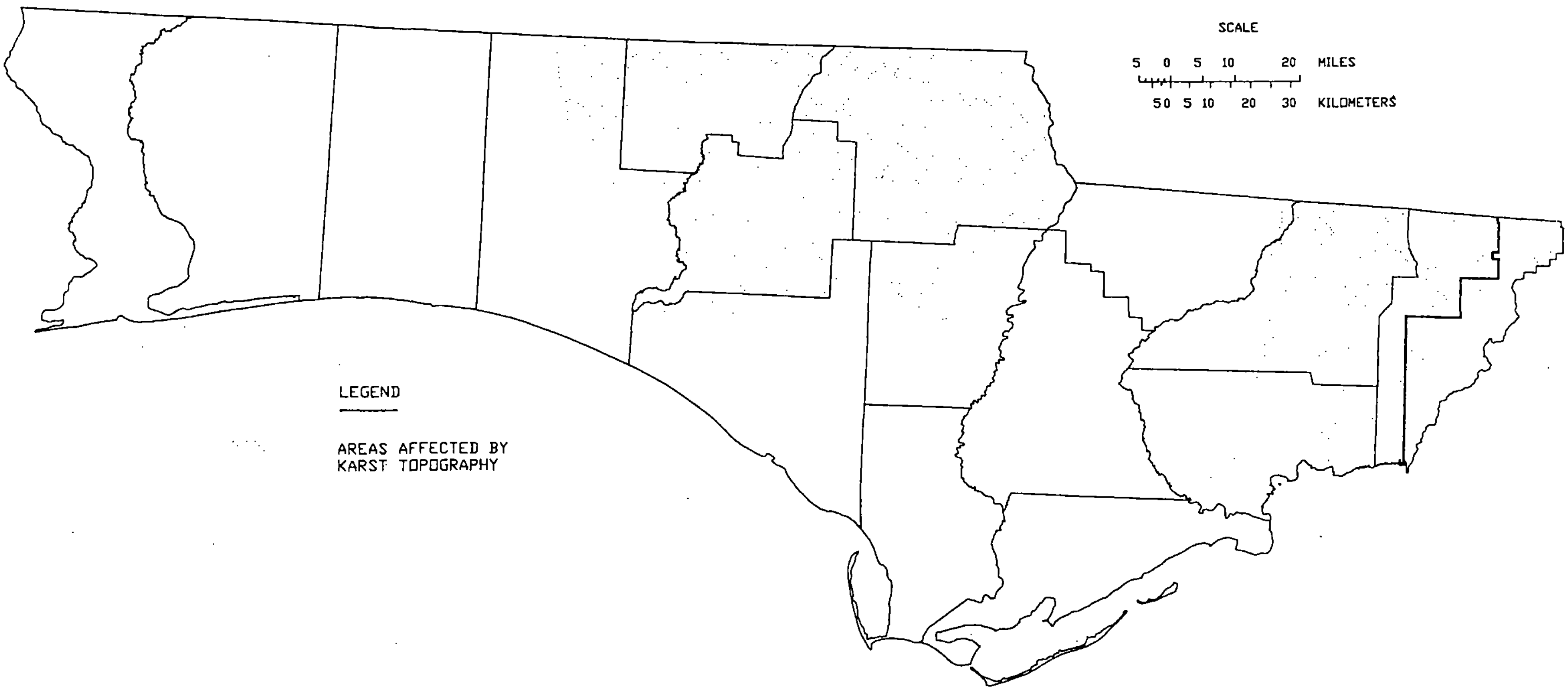


Figure 69. Areas of karst development in NWFWMD

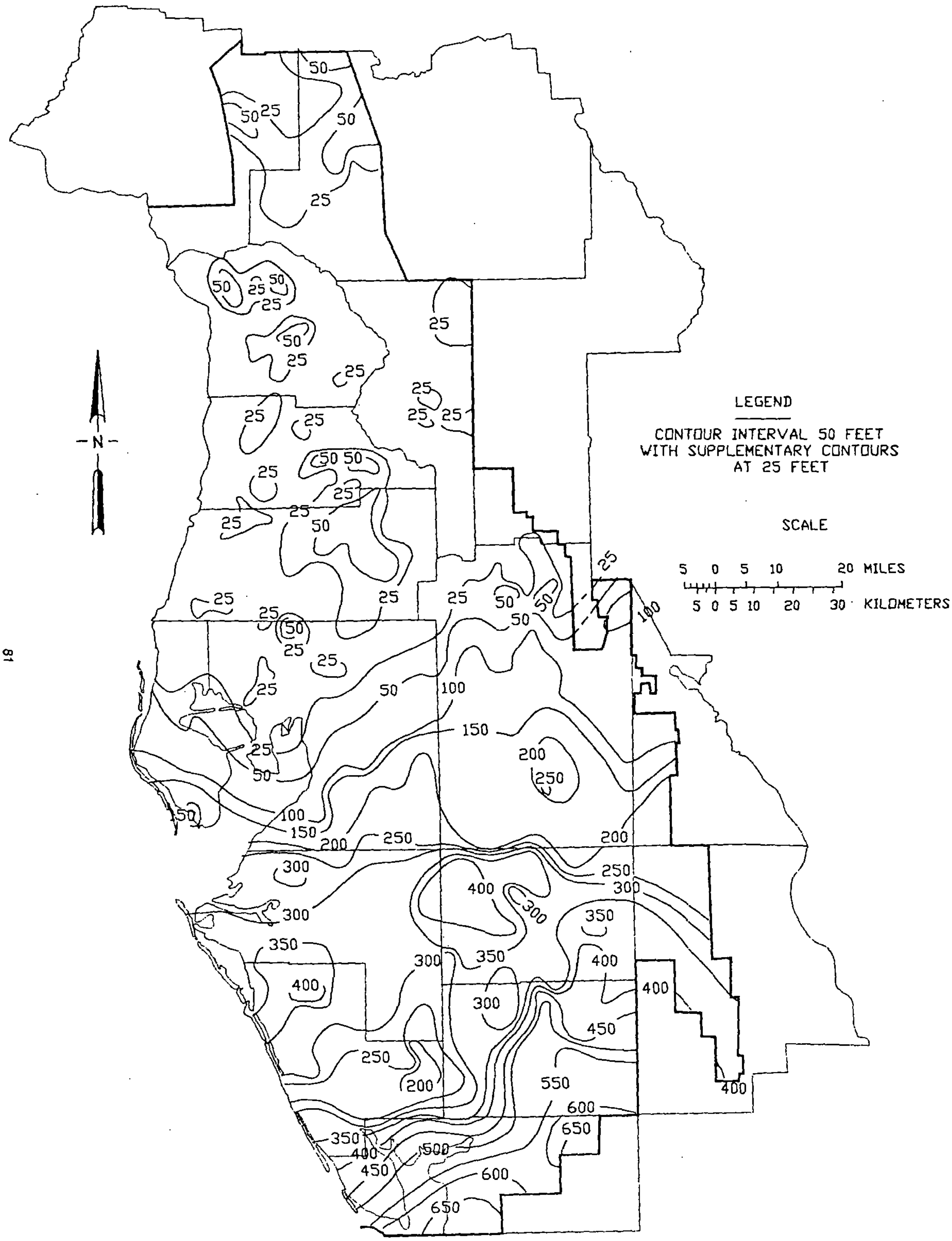


Figure 70. Thickness of the Floridan aquifer system confining bed, SWFWMD (after Buono and others, 1979)

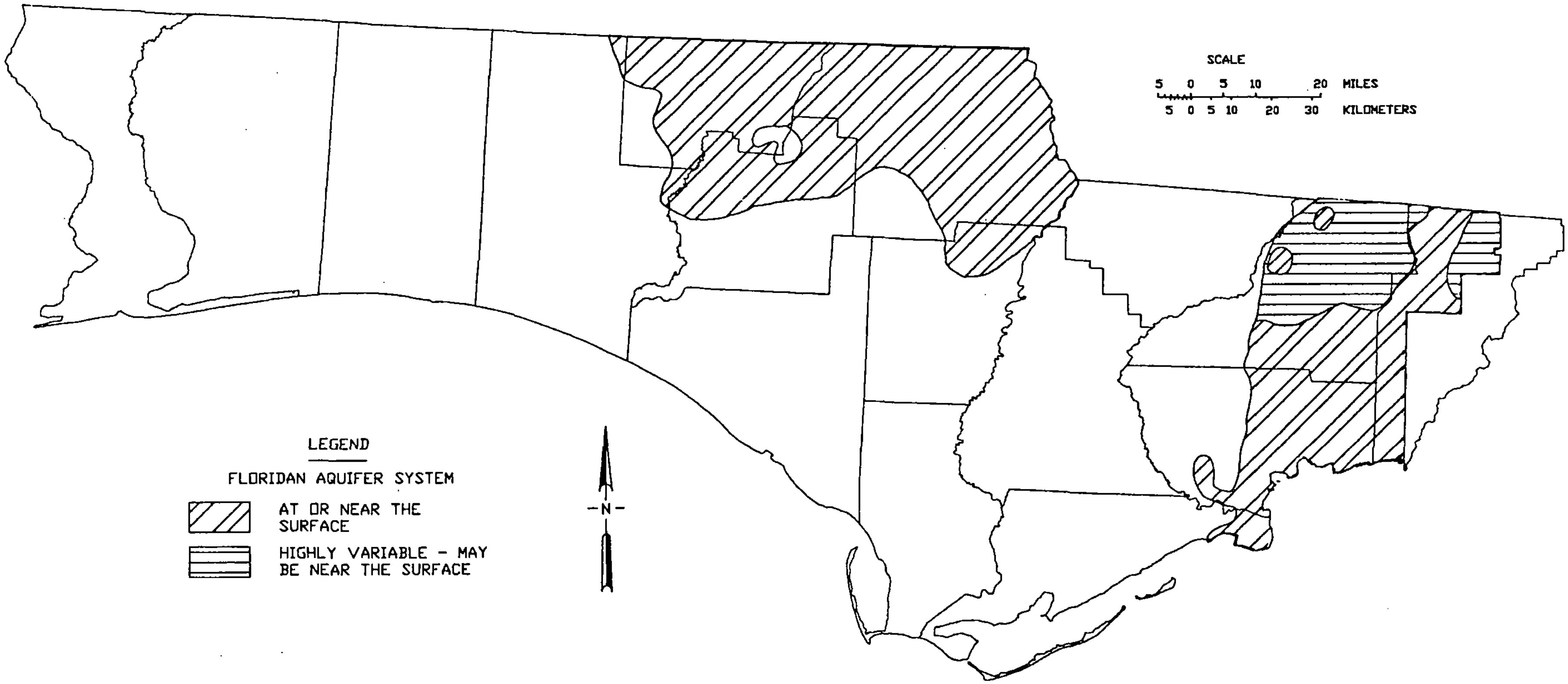


Figure 71. Areas where the Floridan aquifer system is at or near the surface, NWFWMD

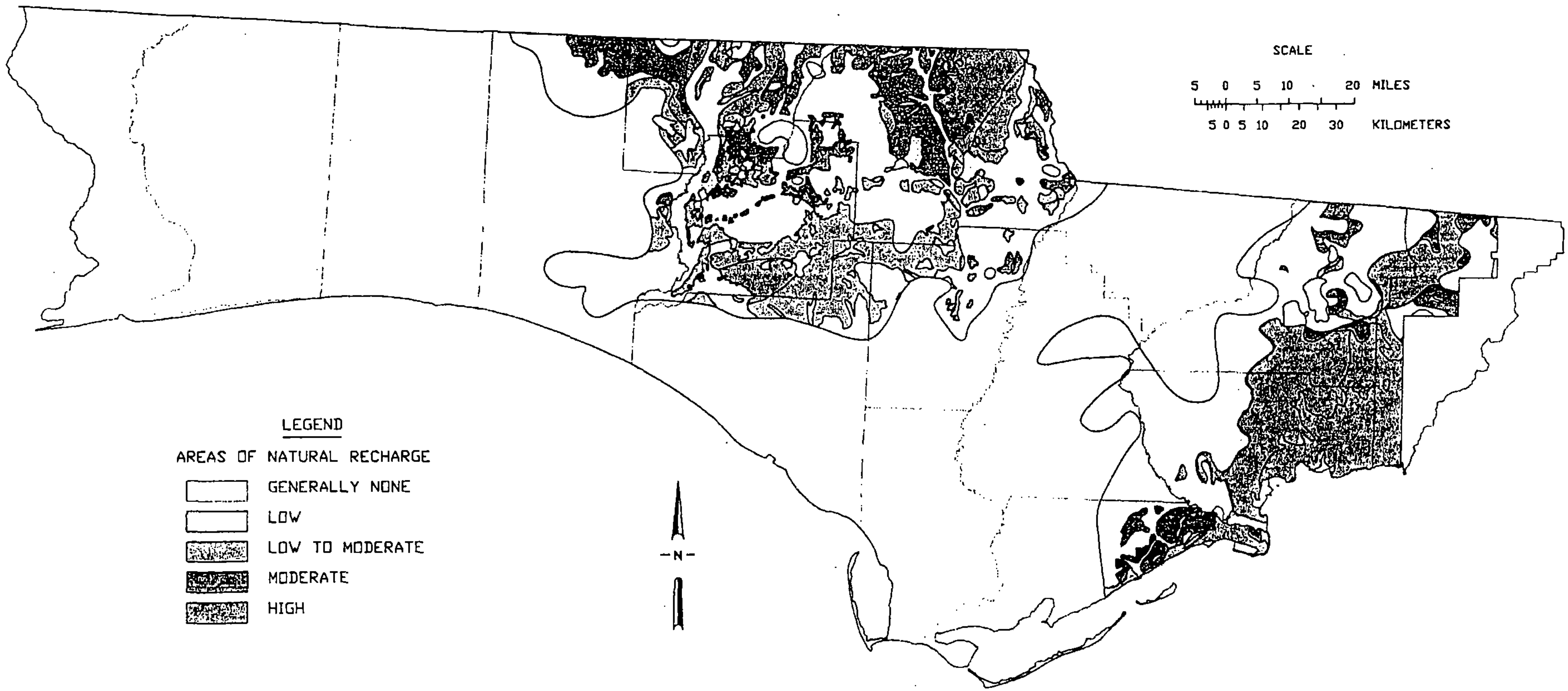


Figure 72. Floridan aquifer system recharge potential, NWFWMD

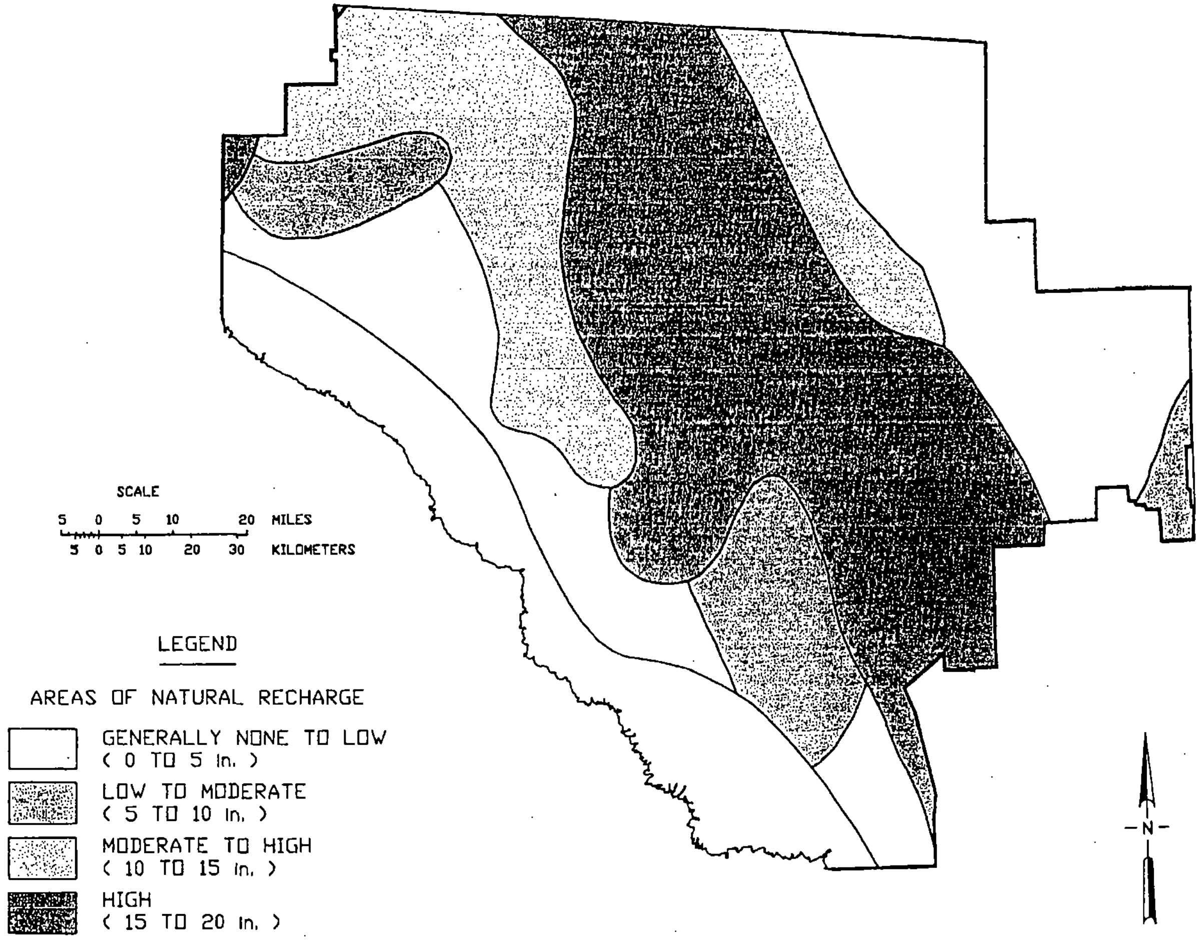


Figure 73. Floridan aquifer system recharge potential, SRWMD

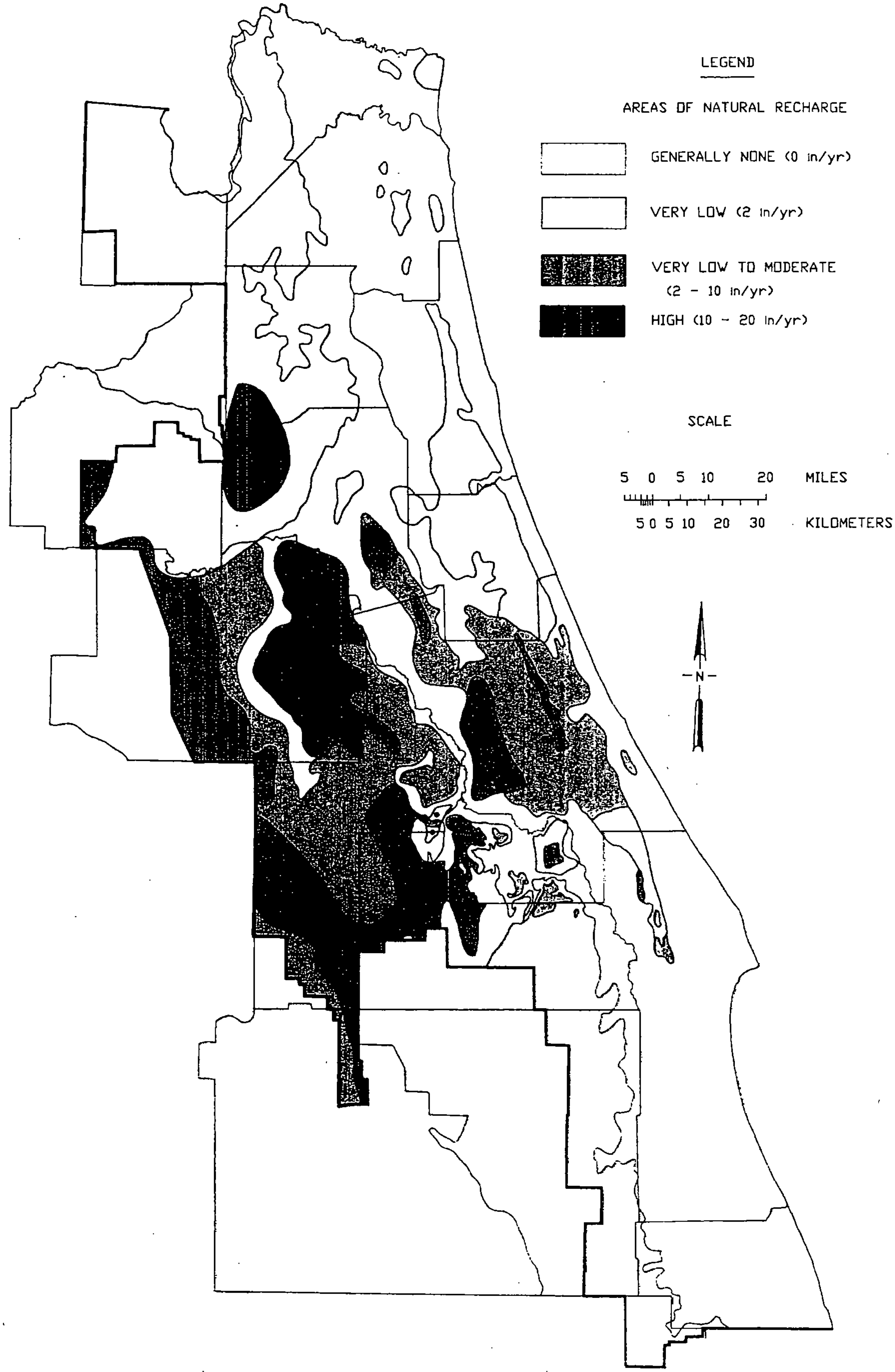


Figure 74. Floridan aquifer system recharge potential, SJRWMD

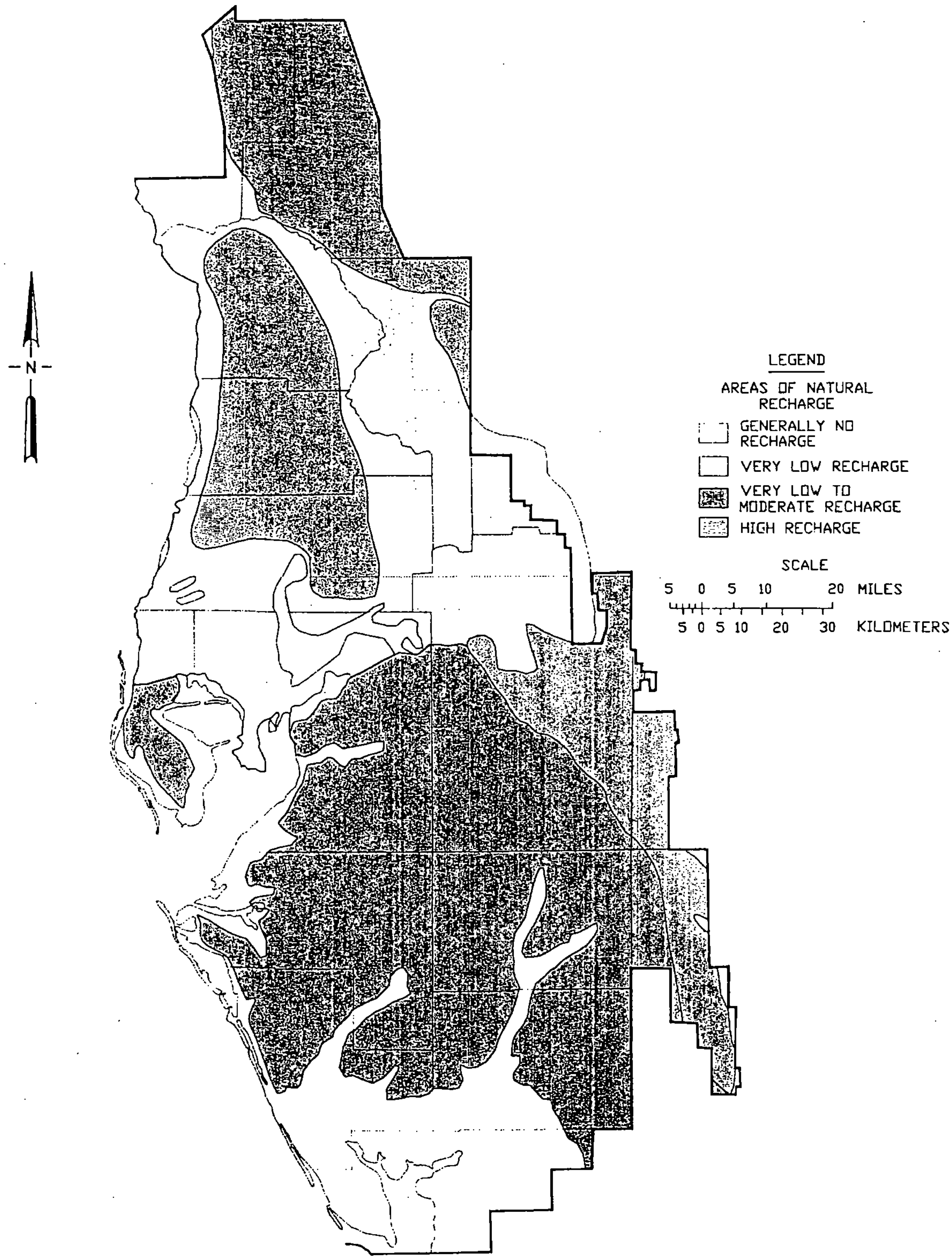


Figure 75. Floridan aquifer system recharge potential, SWFWMD (after Stewart, 1980)

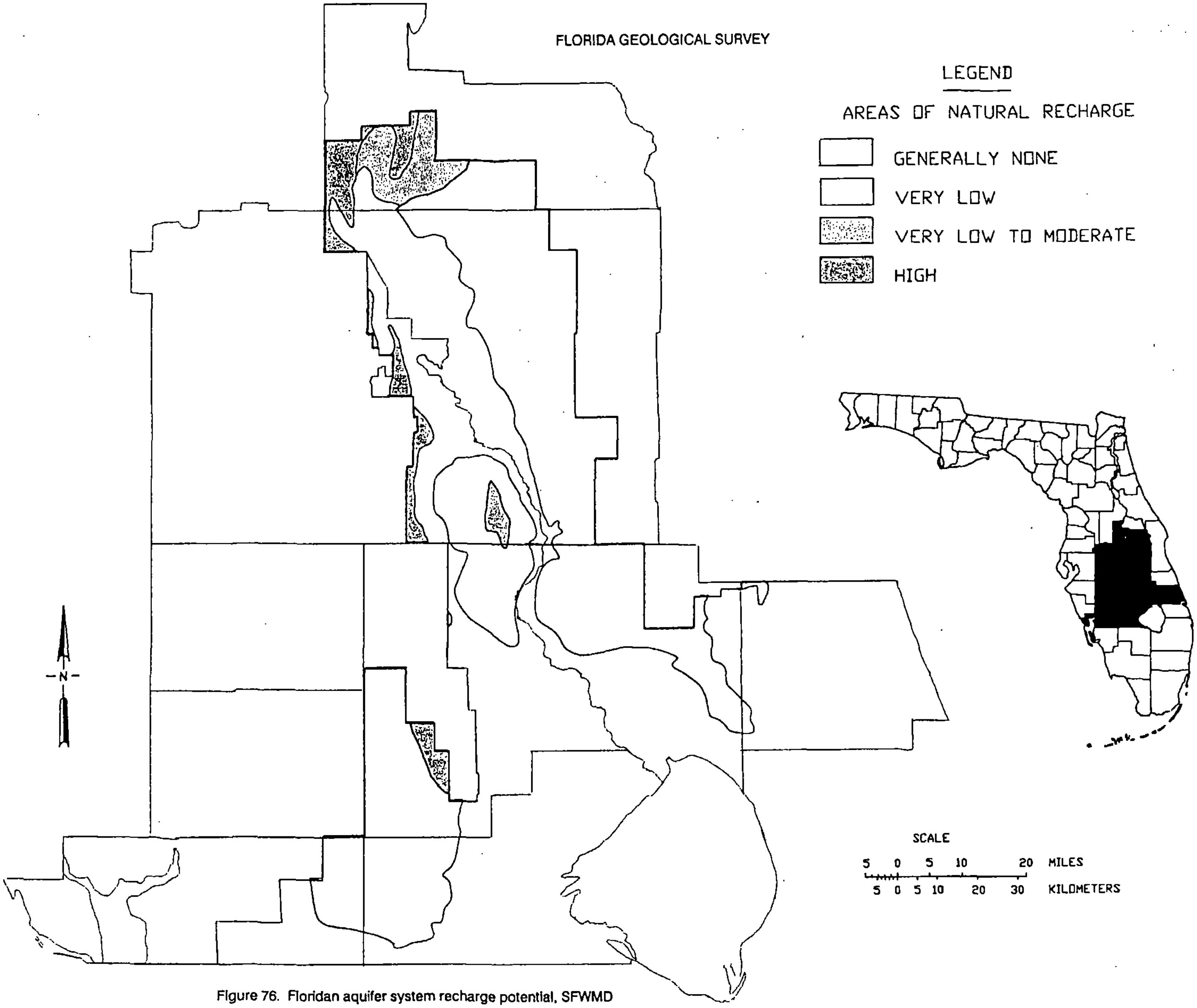


Figure 76. Floridan aquifer system recharge potential, SFWMD

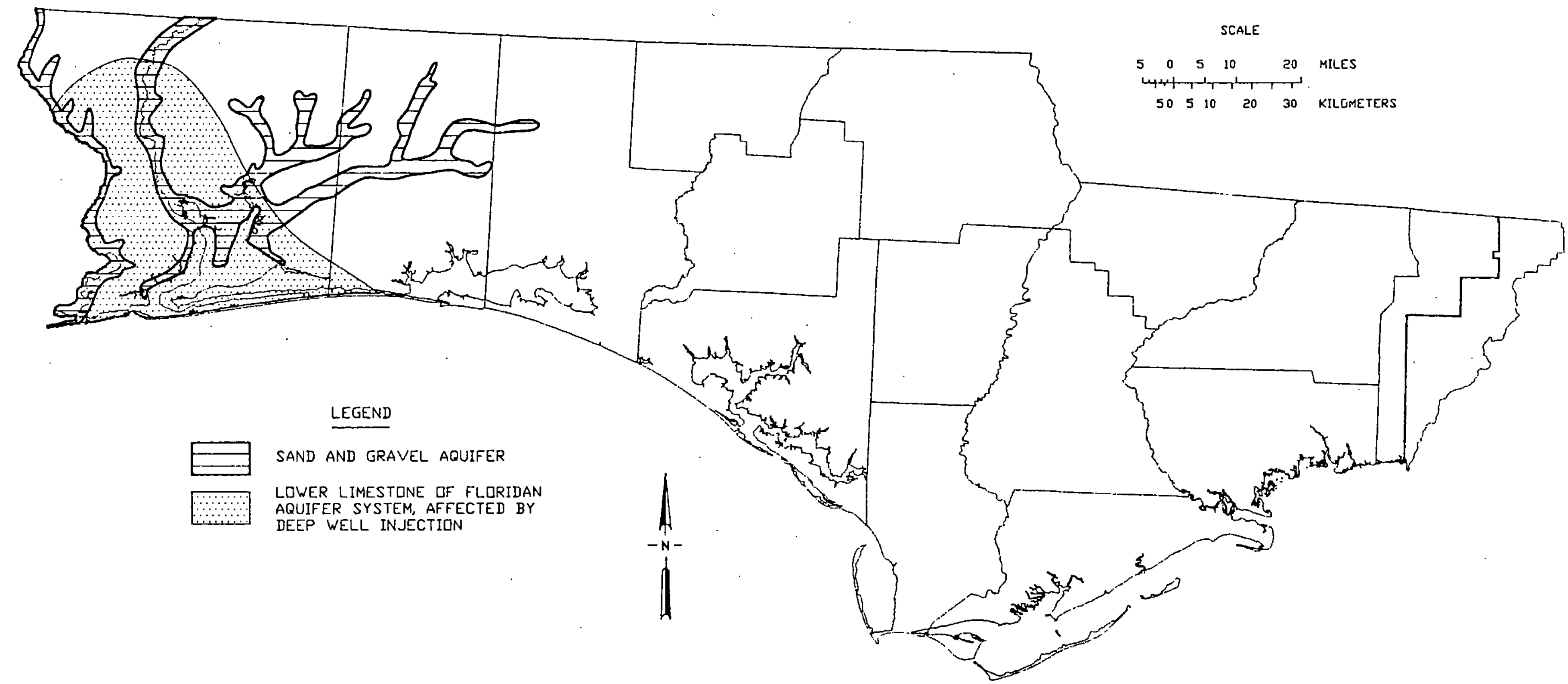


Figure 77. Areas of artesian flow from the sand and gravel aquifer and lower Floridan aquifer system, NWFWMD

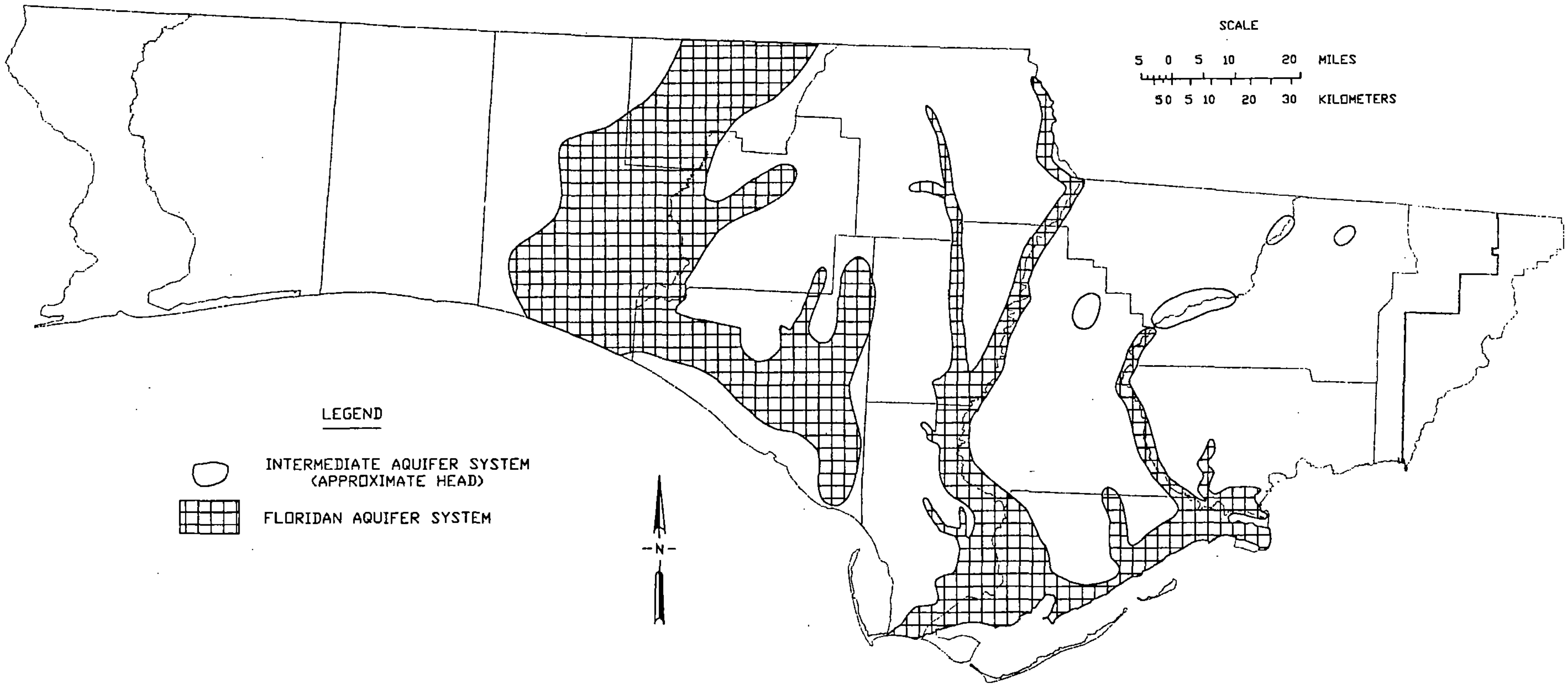


Figure 78. Areas of artesian flow from the intermediate aquifer system and Floridan aquifer system, NWFWMD

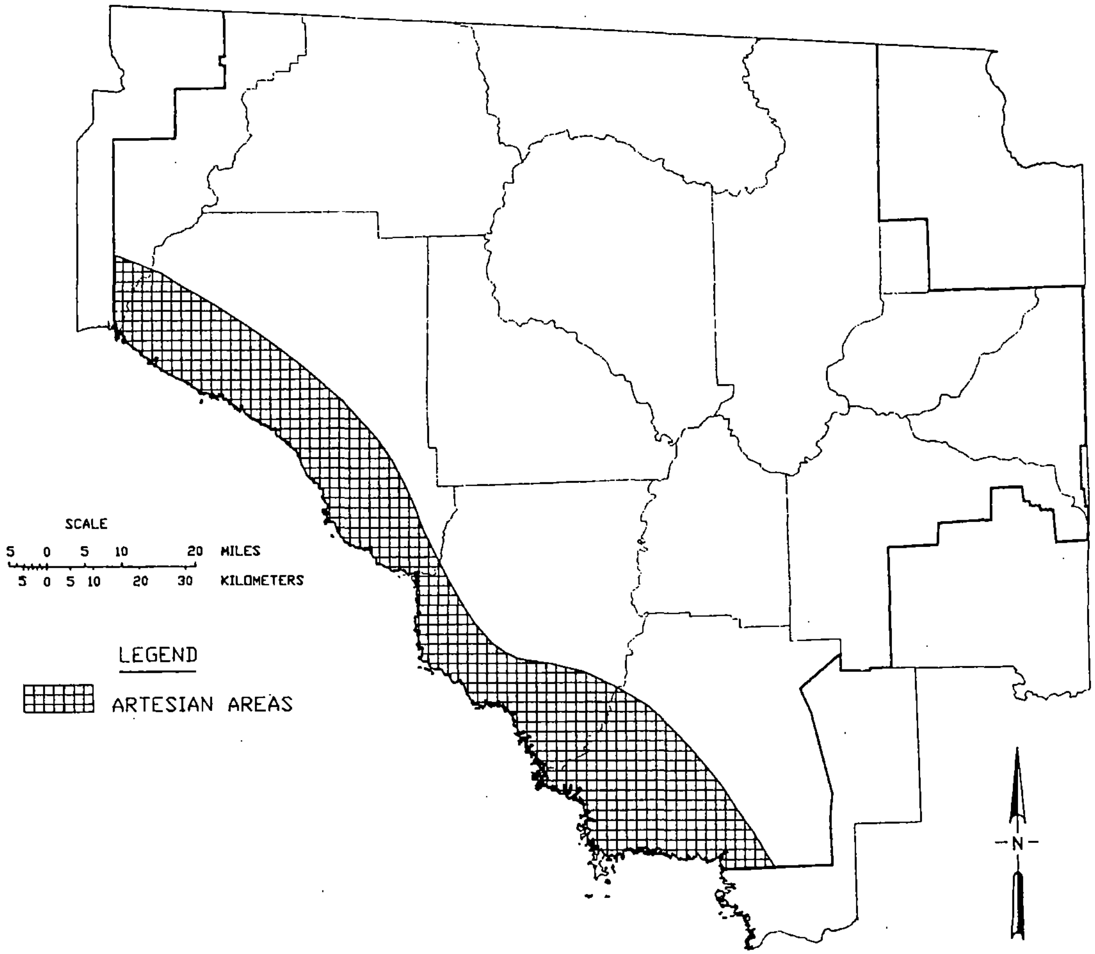


Figure 79. Areas of artesian flow from the Floridan aquifer system, SRWMD

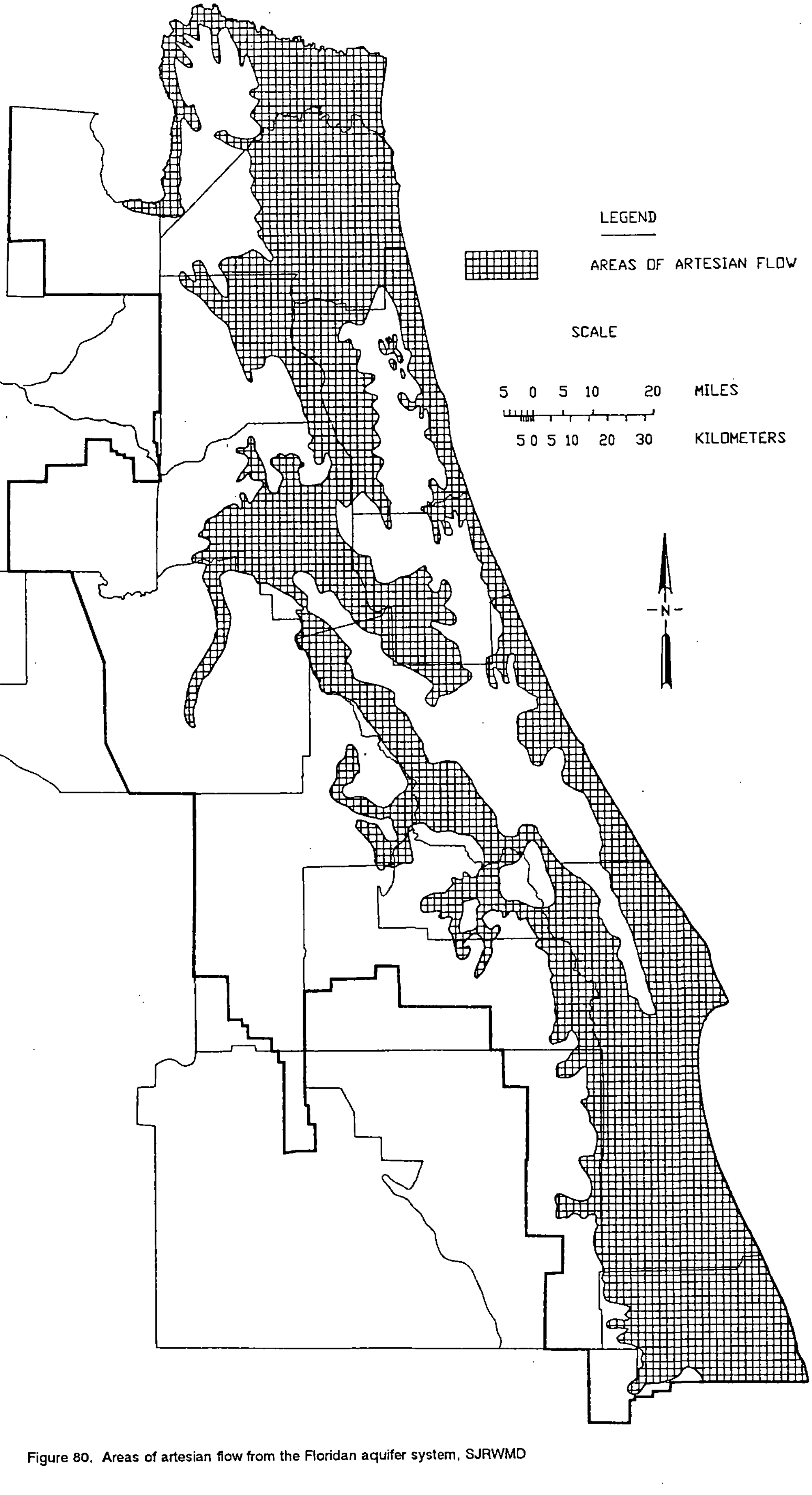


Figure 80. Areas of artesian flow from the Floridan aquifer system, SJRWMD

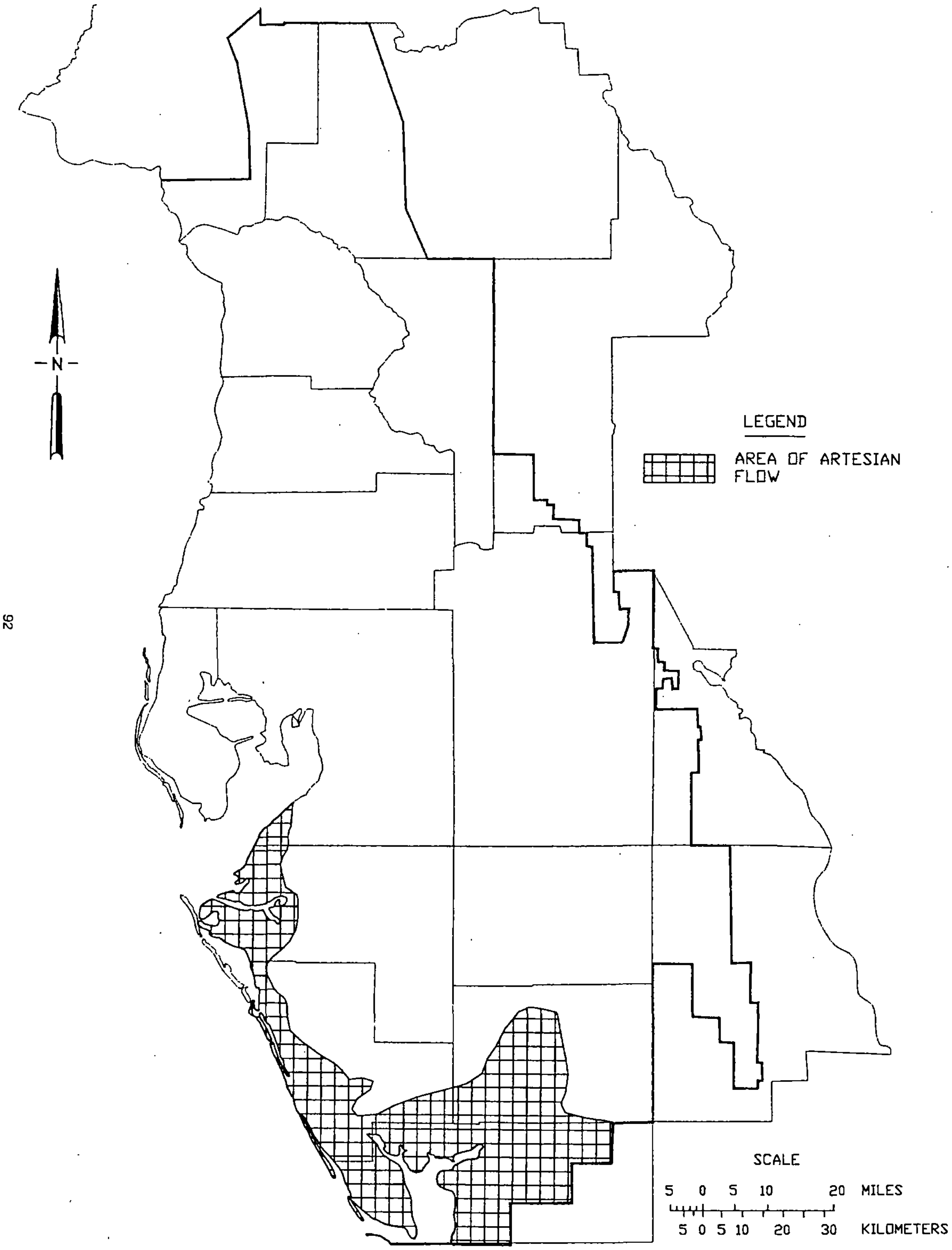


Figure 81. Areas of artesian flow from the Floridan aquifer system, SWFWMD

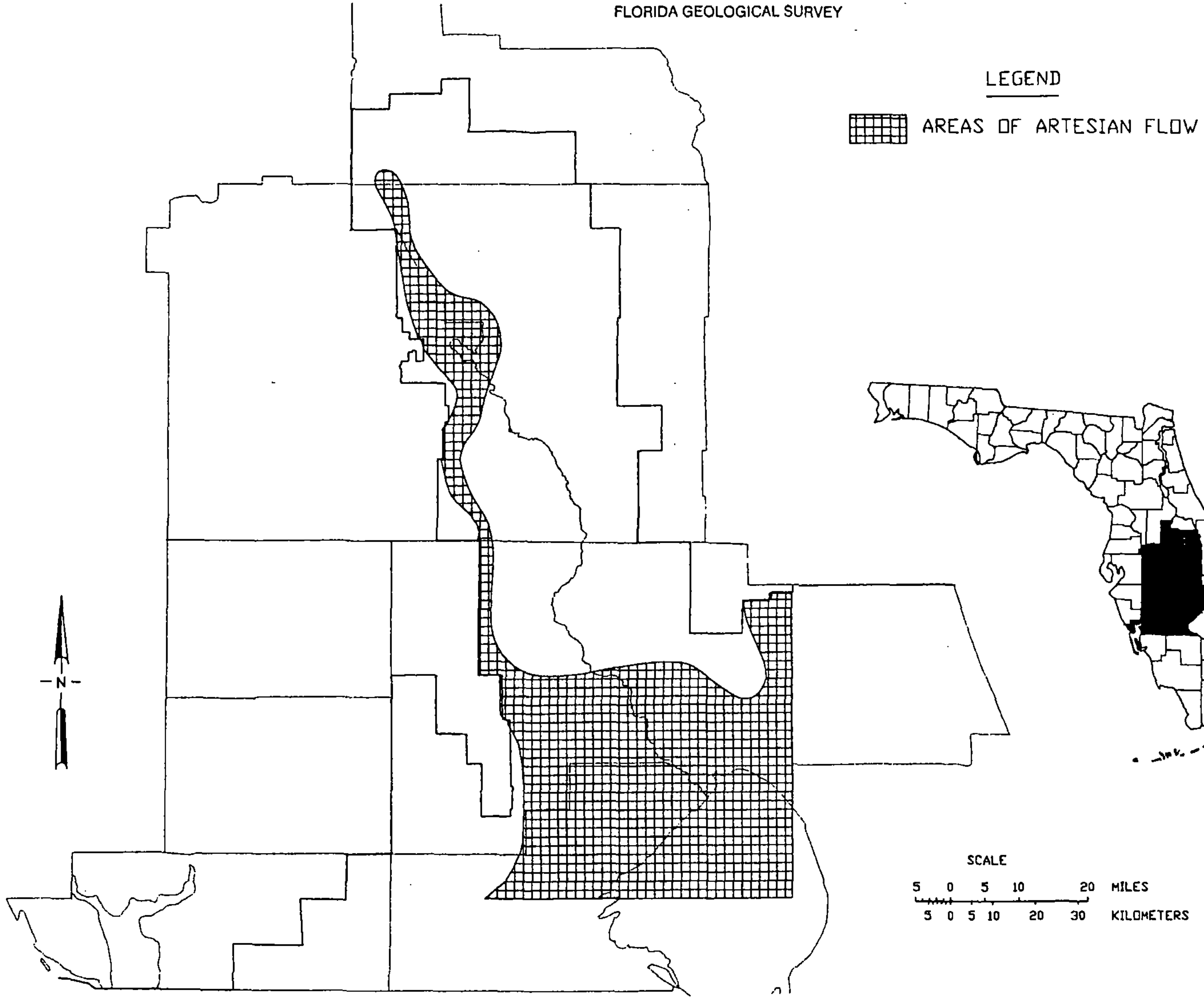


Figure 82. Areas of artesian flow from the Floridan aquifer system, SFWMD

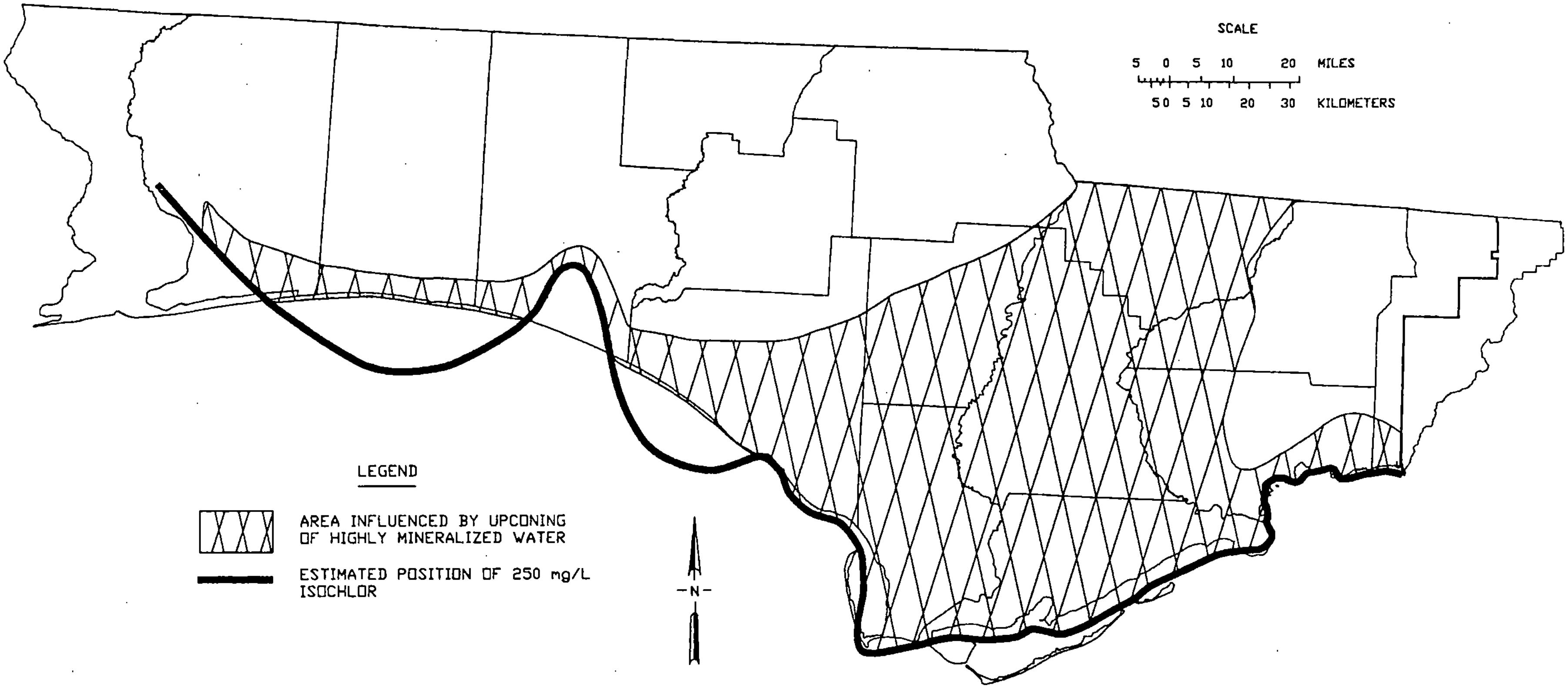


Figure 83. Areas of mineralized water in the Floridan aquifer system, NWFWMD

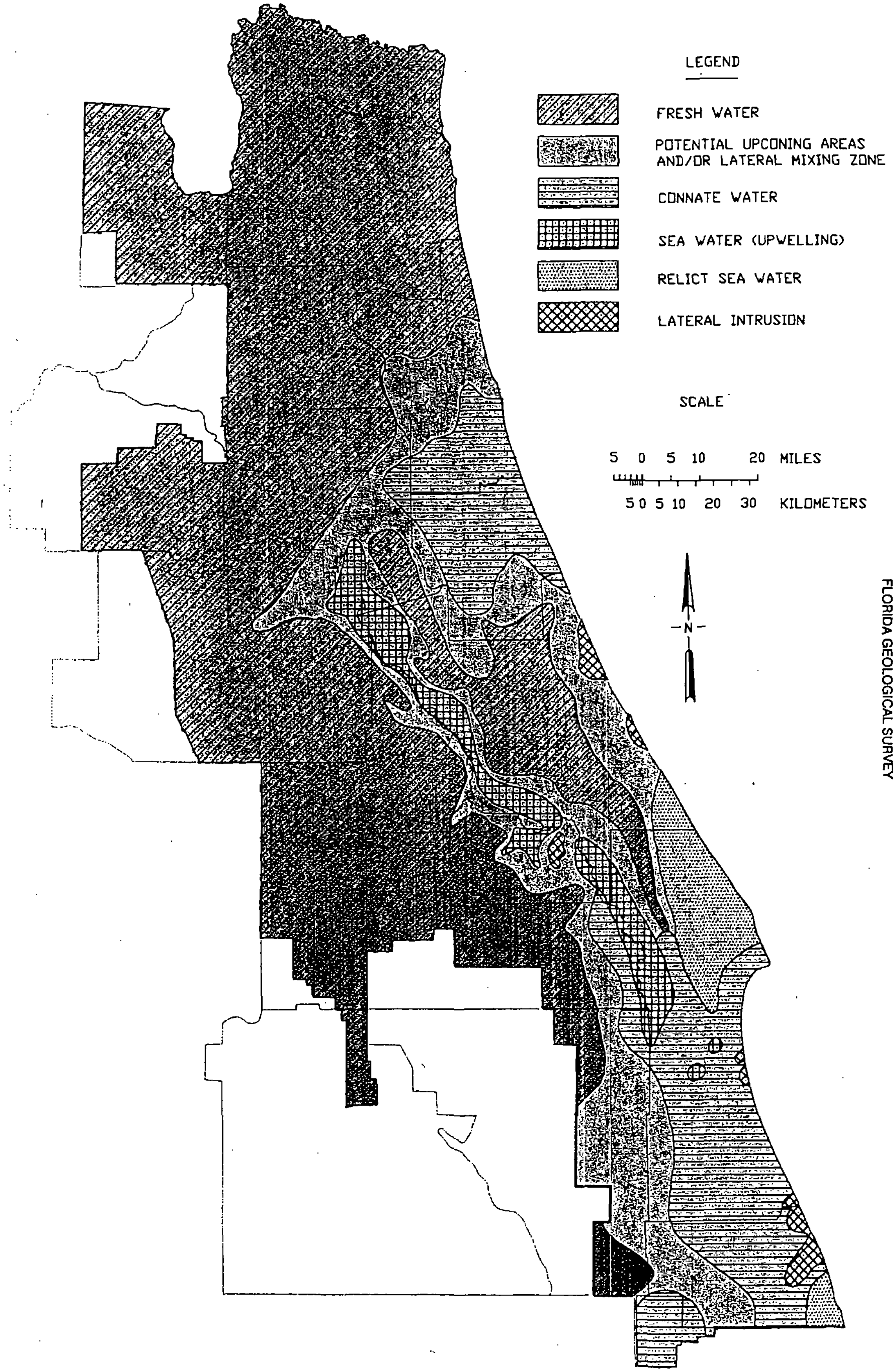


Figure 84. Areas of mineralized water in the Floridan aquifer system, SJRWMD

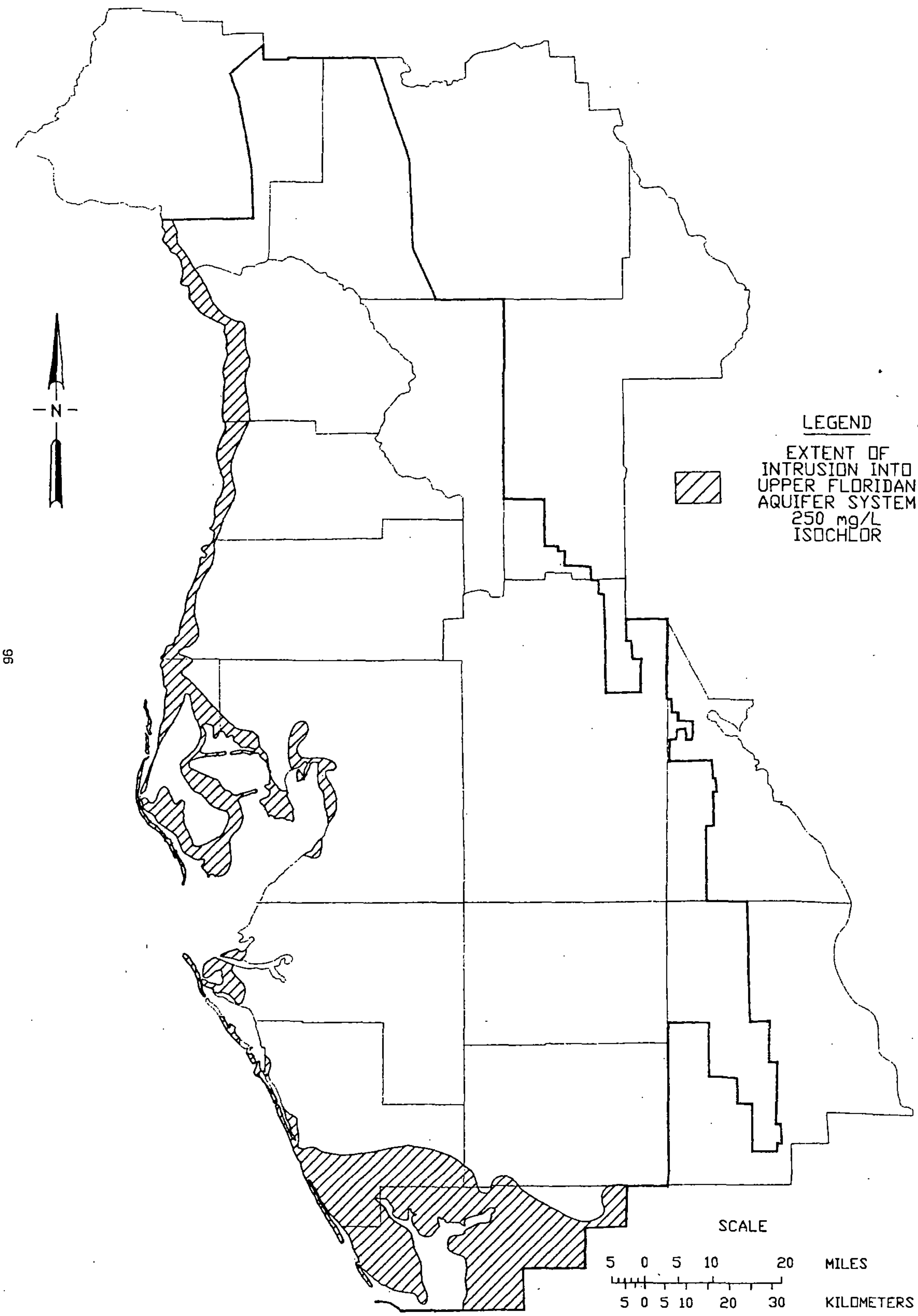


Figure 85. Areas of mineralized water in the Floridan aquifer system, SWFWMD (after Causseaux and Fretwell, 1982)

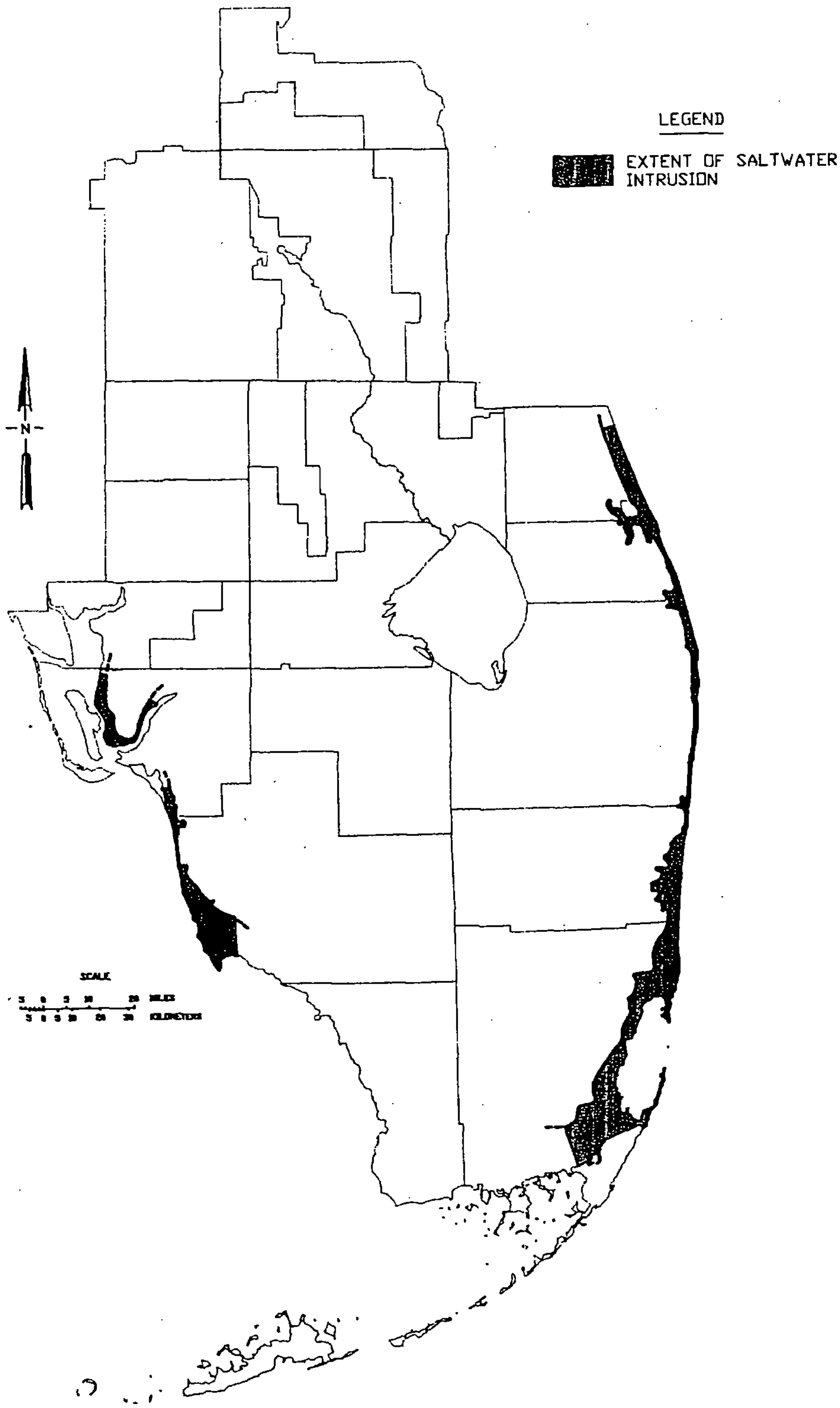


Figure 86. Areas of mineralized water in the Floridan aquifer system, SFWMD

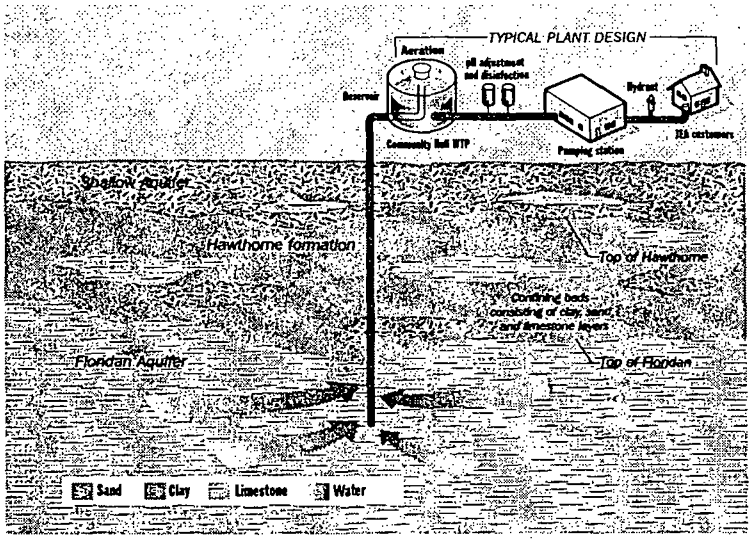
END OF PUBLICATION

2002 ANNUAL WATER QUALITY REPORT

JEA is pleased to present this years Annual Water Quality Report. The information in this booklet is designed to inform you about the source and quality of your drinking water, results from its daily monitoring during 2002 and what they mean; and the services that we deliver to you every day. Our goal is to provide you with a safe and dependable supply of drinking water. We want you to understand the efforts we make to continually improve the water treatment process and protect our water resources. JEA is committed to ensuring the quality of your water and welcome any feedback that can help us make this report work better for you.

The Source Of Your Water

Your water source is the Floridan Aquifer, which is one of the major sources of groundwater in the United States. This highly productive aquifer system underlies all of Florida, southern Georgia, and small parts of adjacent Alabama and South Carolina; a total area of about 100,000 square miles. Our abundant, fresh, clean water supply is obtained by drilling wells deep into the aquifer. The water is then pumped to large water reservoirs where it is aerated, chlorinated for disinfection, pH-adjusted to minimize copper pipe corrosion, and then distributed, via pumping stations, to you and other customers.



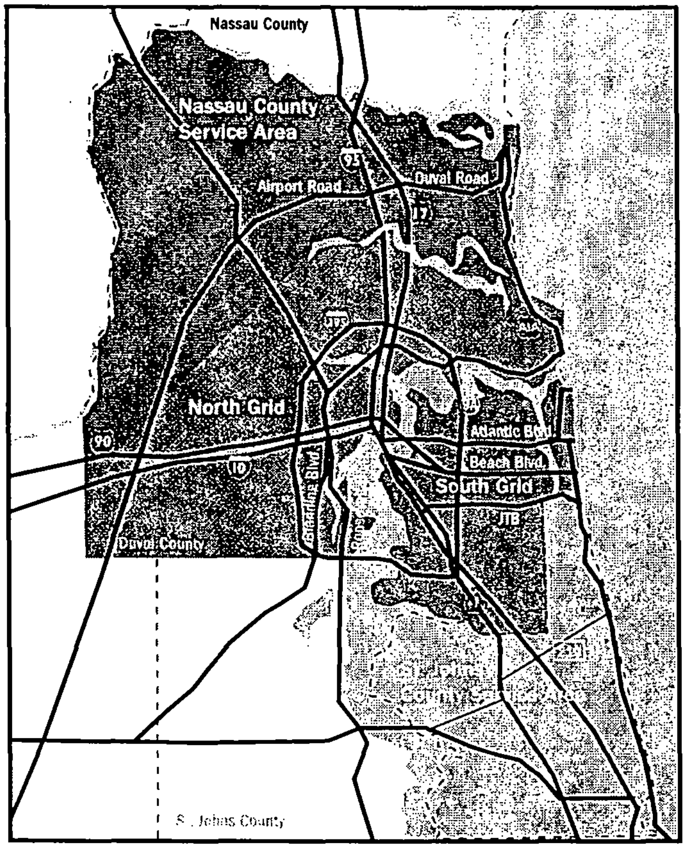
Your Public Water System

All JEA customers will be located in one of the two large existing JEA grids or within several of our smaller independent systems. The North Grid is comprised of 10 water treatment plants (WTP) and is bounded north and west of the St. Johns River. The South Grid is comprised of 23 water treatment plants and is located east of the St. Johns River. Cecil Commerce Center, Mayport, Ortega Hills, and White Shell Bay are hydraulically independent systems that are located within Duval County.

Our Nassau customers are provided water by the Lofton Oaks Grid (Yulee Regional, Otter Run and Lofton Oaks service area). Customers within St. Johns County are provided water by either the St. Johns Forest (independent system), Ponte Vedra Grid (Ponte Vedra North and Corona) or the Ponce De Leon Grid (AIA North, AIA South, and Ponce De Leon) service areas. A listing of the water treatment plants located within the North and South Grids are found within the results of the total hardness analysis report.

Este informe contiene información muy importante sobre su agua de beber. Tradúzcalo o hable con álguien que lo entienda bien.

JEA SERVICE AREA



HARDNESS INFORMATION

The following charts list the Water Treatment Plants (WTP) within the North and South Grids and the results of Total Hardness analyses conducted in 2002. The water hardness for St. Johns and Nassau ranges from 12.4 to 23.4 grains per gallon.

WTP HARDNESS TABLE NORTH GRID

WTP	RESULT (MG/L)	GRAINS PER GALLON
1 Fairfax	280	16.4
2 Highlands	250	14.6
3 Gate Maritime	260	15.2
4 Lakeshore	220	12.7
5 Main Street	260	15.2
6 Marietta	260	15.2
7 McDuff	290	16.9
8 Norwood	230	13.4
9 Oak Hill	150	8.8
10 Southwest	150	8.8

WTP HARDNESS TABLE SOUTH GRID

WTP	RESULT (MG/L)	GRAINS PER GALLON
1 Alderman Park	290	16.9
2 Arlington	440	25.7
3 Brierwood	250	14.6
4 Columbine	290	16.9
5 Community Hall	190	11.1
6 Deerwood I	420	24.6
7 Deerwood III	370	21.6
8 Elvia	280	16.4
9 Hendricks	310	18.1
10 Julington Creek	370	21.6
11 Lake Lucina	290	16.9
12 Love Grove	380	22.2
13 Marshview	330	19.3
14 Monument Road	380	19.3
15 Oakridge	350	20.5
16 Regency	270	15.8
17 Ridenour	310	18.1
18 River Oaks	420	24.6
19 Royal Lakes	420	24.6
20 San Jose	360	21.1
21 Southeast Regional	330	19.3
22 St. Johns North	236	13.8
23 University Park	280	16.4

Ensuring the Safety of Our Drinking Water

To ensure the safety of our drinking water supply, JEA conducts a comprehensive monitoring program. We collect samples from a citywide system of sample taps or faucets and then test them for more than 120 bacteriological and chemical components. JEA also has in place a state-of-the-art operations network that can instantaneously report areas of low pressure, and monitor and control chlorine. These improvements enable us to better monitor our system and offer you an uninterrupted supply of fresh water.

Also, JEA ensures the safety of our drinking water through a Cross-Connection Control/ Backflow Prevention Program. Through a citywide system of backflow prevention assemblies, water that has been delivered to the customer is prevented from being reintroduced into the public water system if a pressure drop occurs. This program protects the water supply from possible contamination.

Important Information About the Data in This Booklet

JEA routinely monitors for contaminants in our drinking water according to federal and state laws, rules, and regulations. Except where indicated otherwise, this report is based on the results of our monitoring for the period of Jan. 1 to Dec. 31, 2002. As authorized and approved by the Environmental Protection Agency, the state has reduced monitoring for certain requirements to less than once per year because the concentrations of these contaminants are not expected to vary significantly from year to year. Some of our data, though representative, is more than one year old.

Frequently Asked Questions About This Report

Why am I getting a Water Quality Report?

The Annual Water Quality Report (or Consumer Confidence Report) is intended for all customers of community water systems. The EPA requires a Water Quality Report under the 1996 Safe Drinking Water Act Amendments. These amendments confirmed the importance of educating the consumer and added new consumer right-to-know responsibilities for water systems.

What do these results in the tables mean?

*The results consist of a listing of all contaminants detected in our drinking water during the sample period. Out of more than 120 contaminants that are routinely tested for, **only those that have been detected appear in the tables.***

Why are there so many contaminants in my drinking water?

Actually, most of the contaminants present in our drinking water occur naturally in the aquifer or are picked up by the water as it travels over the surface of land or through ground. Lead and copper contaminants can occur from household plumbing fixtures.

Important Information Provided By The EPA

The following is general information and much of it does not necessarily pertain to JEA-supplied drinking water because of our deep-well, groundwater source.

IMPORTANT HEALTH INFORMATION

Some people may be more vulnerable to contaminants in drinking water than the general population. Immuno-compromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers.

Environmental Protection Agency (EPA) and Centers for Disease Control (CDC) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbiological contaminants are available from the Safe Drinking Water Hotline at (800)-426-4791.

CONTAMINANT SOURCE INFORMATION

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals and, in some cases, radioactive material, and can pick up substances resulting from the presence of animals or from human activity. Contaminants that may be present in source water include:

(A) Microbial contaminants such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife.

(B) Inorganic contaminants such as salts and metals, which can be naturally occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming.

(C) Pesticides and herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses.

(D) Organic chemical contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and can also come from gas stations, urban stormwater runoff, and septic systems.

(E) Radioactive contaminants, which can be naturally occurring or be the result of oil and gas production and mining activities.

In order to ensure that tap water is safe to drink, EPA prescribes regulations, that limit the amount of certain contaminants in water provided by public water systems. (FDA) Food and Drug Administration regulations establish limits for contaminants in bottled water that must provide the same protection for public health.

Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of contaminants does not necessarily indicate that water poses a health risk.

TERMS AND ABBREVIATIONS

In the data tables you will find many terms and abbreviations that may not be familiar. To help you better understand these terms we've provided the following definitions:

(AL) Action Level - the concentration of a contaminant, which if exceeds, triggers treatment or other requirements that a water system must follow.

Contaminant - any physical, chemical, biological, or radiological substance or matter in water.

(MCL) Maximum Contaminant Level - the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

(MCLG) Maximum Contaminant Level Goal - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

(ND) Non-Detects - means not detected and indicates that the substance was not found by laboratory analysis.

Parts per billion (ppb) or Micrograms per liter (µg/L) – one part by weight of analyte to 1 billion parts by weight of the water sample.

Parts per million (ppm) or Milligrams per liter (mg/L) – one part by weight of analyte to 1 million parts by weight of the water sample.

(pCi/L) Picocuries per Liter - a measure of radioactivity in water

P.O.E. - point of entry into the distribution system.

(TT) Treatment Techniques - a required process intended to reduce the level of a contaminant in drinking water.

(WTP) Water Treatment Plant.

NOTE: MCLs are set at stringent levels. To understand the possible health effects described for many regulated constituents, a person would have to drink two liters of water every day at the MCL level for a lifetime to have a one-in-a-million chance of having the described health effect.

More information about contaminants and potential health effects can be obtained by calling the Environmental Protection Agency's Safe Drinking Water Hotline at (800)426-4791.

NOTE: In addition to required unregulated contaminant sampling, EPA has established the UCMR or Unregulated Contaminant Monitoring Rule. This rule will help to determine if previously unregulated contaminants should become regulated (and therefore have a MCL and a MCLG). In this new series of testing JEA had no detections.

North Grid

Microbiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Percentage of Monthly Positive Samples	MCLG	MCL	Likely Source of Contamination
Total Coliform Bacteria	Monthly	N	0.5	0	*	Naturally present in the environment.

* For systems collecting at least 40 samples per month: presence of coliform bacteria in more than 5% of monthly samples.

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Radiological Contaminants							
Gross Alpha Particle (pCi/l)	07/02 08/02	N	6.4	ND-6.4	0	15	Erosion of natural deposits.
Radium 226 or combined radium (pCi/l)	12/02	N	0.2	N/A	0	5	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	07/02 08/02	N	0.029	ND- 0.029	2	2	Discharge of drilling waste; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	07/02 08/02	N	0.74	0.40 - 0.74	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Nitrate (Nitrogen) (ppm)	07/02 08/02	N	0.47	ND - 0.47	10	10	Naturally occurring in aquifer; erosion of natural deposits.
Sodium (ppm)	07/02 08/02	N	21	ND- 21	N/A	160	Salt water intrusion, leaching from soil.
Synthetic Organic Contaminants Including Pesticides and Herbicides							
Diquat (ppb)	07/02	N	0.48	ND - 0.48	20	20	Runoff from herbicide use.

Note: A verification sample of diquat was taken in December 2002 and resulted in no detection of the contaminant.

Stage 1 Disinfectant/Disinfection By-Product (D/DBP) Parameter

TTHM (ppb)	Quarterly 2002	N	34.5	9.7 - 96.3	N/A	100	By-product of drinking water disinfection.

Note: The result in the Level Detected column for TTHMs is the highest of the four quarterly running annual averages of results from all sampling sites. The quarterly running annual averages were calculated during the first, second, third, and fourth quarters of 2002.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	07/00	N	0.60	0 of 60	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	07/00	N	2.2	0 of 60	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

South Grid

Microbiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Percentage of Monthly Positive Samples	MCLG	MCL	Likely Source of Contamination
Total Coliform Bacteria	Monthly	N	3.05	0	*	Naturally present in the environment.

* For systems collecting at least 40 samples per month: presence of coliform bacteria in more than 5% of monthly samples.

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Total Number of Positive Samples for the Year	MCLG	MCL	Likely Source of Contamination
Fecal coliform or E.coli	05/02	N	2	0	*	Human and animal fecal waste.

* A routine sample and repeat sample are total coliform positive, and one is also fecal coliform or E. Coli positive

Radiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Gross Alpha Particle (pCi/L)	8/02	N	1.7	ND - 1.7	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	03/02 07/02 08/02	N	0.034	ND- 0.034	2	2	Discharge of drilling waste; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	03/02 07/02 08/02	N	1.00	0.003 - 1.00	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Lead (point of entry) (ppb)	03/02 07/02 08/02	N	2.5	ND - 2.5	N/A	15	Residue from man-made pollution such as auto emissions and paint; lead pipe; casing; and solder.
Nitrate (Nitrogen) (ppm)	03/02 07/02 08/02	N	0.23	ND - 0.23	10	10	Naturally occurring in aquifer; erosion of natural deposits.
Sodium (ppm)	03/02 07/02 08/02	N	50	ND - 50	N/A	160	Salt water intrusion, leaching from soil.
Synthetic Organic Contaminants including Pesticides and Herbicides							
Diquat (ppb)	07/02	N	0.53	ND - 0.53	20	20	Runoff from herbicide use.

Note: A verification sample of diquat was taken in December 2002 and resulted in no detection of the contaminant.

Stage 1 Disinfectant/Disinfection By-Product (D/DBP) Parameter

TTHM (ppb)	Quarterly 2002	N	39.6	3.3-146	N/A	100	By-product of drinking water disinfection.

Note: The result in the Level Detected column for TTHMs is the highest of the four quarterly running annual averages of results from all sampling sites. The quarterly running annual averages were calculated during the first, second, third, and fourth quarters of 2002.

Secondary Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Result	Range of Results	MCLG	MCL	Likely Source of Contamination
Total Dissolved Solids (ppm)	03/02 07/02 08/02	N	** 680	290-680	N/A	500	Natural occurrence from soil leaching.

** Note: TDS may be greater than 500, if no other Secondary Contaminant MCL is exceeded.

SOUTH GRID CONTINUED

Lead and Copper (Tap Water)

CONTAMINANT AND UNIT OF MEASUREMENT	DATES OF SAMPLING (MO/YR)	AL VIOLATION Y/N	90TH PERCENTILE RESULT	NO. OF SAMPLING SITES EXCEEDING THE AL	MCLG	AL (ACTION LEVEL)	LIKELY SOURCE OF CONTAMINATION
Copper (ppm)	7/00	N	0.51	0 of 64	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	7/00	N	5.0	1 of 64	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

CECIL COMMERCE CENTER GRID

Radiological Contaminants

CONTAMINANT AND UNIT OF MEASUREMENT	DATES OF SAMPLING (MO/YR)	MCL VIOLATION Y/N	LEVEL DETECTED	RANGE OF RESULTS	MCLG	MCL	LIKELY SOURCE OF CONTAMINATION
Gross Alpha Particle (pCi/L)	05/01	N	1.0	N/A	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	07/02	N	0.016	0.015-0.016	2	2	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	07/02	N	0.31	0.30-0.31	4	4	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories.
Nitrate (Nitrogen) (ppm)	07/02	N	0.1	ND-0.1	10	10	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits.
Sodium (ppm)	07/02	N	60	55-60	N/A	160	Salt water intrusion, leaching from soil.

Lead and Copper (Tap Water)

CONTAMINANT AND UNIT OF MEASUREMENT	DATES OF SAMPLING (MO/YR)	AL VIOLATION Y/N	90TH PERCENTILE RESULT	NO. OF SAMPLING SITES EXCEEDING THE AL	MCLG	AL (ACTION LEVEL)	LIKELY SOURCE OF CONTAMINATION
Copper (ppm)	09/02	N	0.247	0 of 30	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	09/02	N	12.7	1 of 30	0	15	Corrosion of household plumbing systems, erosion of natural deposits.

Mayport WTP

Inorganic Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Arsenic (ppb)	07/02	N	5.2	N/A	N/A	50	Erosion of natural deposits; runoff from orchards; runoff from glass and electronics production wastes.
Barium (ppm)	07/02	N	0.029	N/A	2	2	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	07/02	N	0.65	N/A	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer and aluminum factories.
Sodium (ppm)	07/02	N	18	N/A	N/A	160	Salt water intrusion; leaching from soil.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	08/02	N	0.045	0 of 11	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	08/02	N	1.8	1 of 11	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

Ortega Hills WTP

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Inorganic Contaminants							
Fluoride (ppm)	08/02	N	0.44	N/A	4	4	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories.
Nitrate (Nitrogen) (ppm)	08/02	N	0.090	N/A	NA	10	Runoff from fertilizer use; leaching from septic tanks, sewage, erosion or natural deposits.
Radiological Contaminants							
Gross Alpha Particle (pCi/L)	04/00	N	1.7	N/A	0	15	Erosion of natural deposits.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	7/00	N	0.100	0 of 20	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood.

White Shell Bay WTP

Radiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Gross Alpha Particle (pCi/L)	05/01	N	1.0	N/A	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	08/02	N	0.027	N/A	2	2	Discharge of drilling waste; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	08/02	N	0.71	N/A	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Sodium (ppm)	08/02	N	15	N/A	N/A	160	Salt water intrusion; leaching from soil.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	6-8/01	N	0.15	0 of 5	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	6-8/01	N	3.2	0 of 5	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

St. Johns Forest WTP

Microbiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Monthly Number of Positive Samples	MCLG	MCL	Likely Source of Contamination
Total Coliform Bacteria	07/02	Y	2	0	*	Naturally present in the environment.

* For systems collecting fewer than 40 samples per month: presence of coliform bacteria in 1 or more samples collected during a month. Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially-harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.

Radiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Gross Alpha Particle (pCi/L)	03/02	N	1.3	N/A	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Fluoride (ppm)	03/02	N	0.57	N/A	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Sodium (ppm)	03/02	N	17	N/A	N/A	160	Salt water intrusion; leaching from soil.

Secondary Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Result	Range of Results	MCLG	MCL	Likely Source of Contamination
Total Dissolved Solids (ppm)	03/02 12/02	*Y	640	N/A	N/A	500	Natural occurrence from soil leaching.
Sulfate (ppm)	03/02 12/02	*Y	280	N/A	N/A	250	Natural occurrence from soil leaching.

*While the MCL level was exceeded for TDS and Sulfate, high levels of this contaminant do not show an adverse health effect.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	09/02	N	0.29	0 of 5	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	09/02	N	3.0	0 of 5	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

Lofton Oaks Grid

Inorganic Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Barium (ppm)	03/02	N	0.034	0.027 - 0.034	2	2	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	03/02	N	0.74	0.53-0.74	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer and aluminum factories.
Nitrate (ppm)	03/02	N	0.12	ND - 0.12	10	10	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits.
Sodium (ppm)	03/02	N	26	20 - 26	N/A	160	Salt water intrusion; leaching from soil.

Secondary Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Result	Range of Results	MCLG	MCL	Likely Source of Contamination
Odor (threshold odor number)	12/02	*Y	4.0	ND – 4.0	N/A	3	Naturally occurring organics.
Total Dissolved Solids (ppm)	03/02 12/02	*Y	540	390 – 540	N/A	500	Natural occurrence from soil leaching.

*While the MCL level was exceeded for TDS and Odor, high levels of this contaminant do not show an adverse health effect.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	09/02	N	0.09	0 of 20	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	09/02	N	3.2	0 of 20	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

Ponte Vedra Grid

Microbiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	MCL Violation Y/N	Highest Monthly Number of Positive Samples	MCLG	MCL	Likely Source of Contamination
Total Coliform	Monthly	Y	2	0	*	Naturally present in the environment.

* For systems collecting fewer than 40 samples per month: presence of coliform bacteria in 1 or more samples collected during a month. Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially-harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.

Radiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Gross Alpha Particle (pCi/L)	03/02	N	1.5	ND - 1.5	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	03/02	N	0.034	0.026-0.034	2	2	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	03/02	N	0.82	0.80 - 0.82	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Sodium (ppm)	03/02	N	47	21 - 47	N/A	160	Salt water intrusion; leaching from soil.
Stage 1 Disinfectant/Disinfection By-Product (D/DBP) Parameter							
TTHM (ppb)	Quarterly 2002	N	24.6	13.8-35.4	N/A	100	By-product of drinking water disinfection.

Secondary Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Total Dissolved Solids (ppm)	03/02	N	**600	530-600	N/A	500	Natural occurrence from soil leaching.

** Note: TDS may be greater than 500, if no other Secondary Contaminant MCL is exceeded.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (Mo/Yr)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	09/00	N	0.62	0 of 47	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	09/00	N	0	0 of 47	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

Ponce De Leon Grid

Radiological Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Level Detected	Range of Results	MCLG	MCL	Likely Source of Contamination
Gross Alpha Particle (pCi/L)	03/02	N	3.4	2.2 - 3.4	0	15	Erosion of natural deposits.
Inorganic Contaminants							
Barium (ppm)	03/02	N	0.020	0.015 - 0.020	2	2	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits.
Fluoride (ppm)	03/02	N	1.10	0.93 - 1.10	4	4	Erosion of natural deposits; water additive which promotes strong teeth; discharge from fertilizer factories.
Sodium (ppm)	03/02	N	76	46-76	N/A	160	Salt water intrusion; leaching from soil.

Secondary Contaminants

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	MCL Violation Y/N	Highest Result	Range of Results	MCLG	MCL	Likely Source of Contamination
Total Dissolved Solids (ppm)	03/02 12/02	*Y	810	600-810	N/A	500	Natural occurrence from soil leaching.
Sulfate (ppm)	03/02 12/02	*Y	270	160-270	N/A	250	Natural occurrence from soil leaching.

*While the MCL level was exceeded for TDS and Sulfate, high levels of this contaminant do not show an adverse health effect.

Lead and Copper (Tap Water)

Contaminant and Unit of Measurement	Dates of Sampling (MO/YR)	AL Violation Y/N	90th Percentile Result	No. of Sampling Sites Exceeding the AL	MCLG	AL (Action Level)	Likely Source of Contamination
Copper (ppm)	09/02	N	0.17	0 of 20	1.3	1.3	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives.
Lead (ppb)	09/02	N	6.8	0 of 20	0	15	Corrosion of household plumbing systems; erosion of natural deposits.

UnitedWater.

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JEA And United Water Complete $219 Million Transaction

- Rates to drop about 25 percent for typical previous United Water Florida customer
- Innovative, long-term public-private partnership formed
- Employees offered positions with either JEA or United Water

JACKSONVILLE, FL, December 28, 2001 — JEA, the largest municipal electric, water and sewer utility in Florida, and United Water, one of the largest water services company in the United States, today completed the sale of United Water's regulated properties in Florida to JEA for $219 million. JEA and United Water also formed a 20-year public-private partnership for United Water to operate some of the facilities JEA acquired through this purchase.

Michael Hightower, chairman of JEA's Board of Directors, said, "The completion of this sale means that beginning today, more than 30,000 First Coast families will spend less money for high quality water and sewer services. The typical previous United Water customer who uses an average amount of water (900 cubic feet or 6,732 gallons) each month will see their bills go down about 25 percent. Since JEA provides electric service to most of these customers, they can pass on savings through lower rates, long-term rate stability and the convenience of getting all three utilities from the same provider.

"The public-private partnership agreement benefits all stakeholders," said Patrick Verschelde, chairman and chief executive officer of Ondeo Services, the parent company of United Water. "Customers will enjoy low, stable rates thanks to the consolidation of water and wastewater systems. The employees have comparable positions either with JEA or within the United Water organization. And United Water creates value through the sale and long-term operations and maintenance agreement with JEA."

JEA will consolidate facilities and assume all responsibilities for the water and sewer systems. United Water will continue to provide operation and maintenance service at the Monterrey sewer treatment plant in Duval County and at water and sewer facilities in St. Johns and Nassau counties.

United Water, one of the largest water services companies in the U.S., provides water and wastewater service to more than 7.5 million people. The company is a wholly owned subsidiary of Ondeo Services, the world's leader in water and wastewater management services, serving more than 115 million people in over 130 countries. Ondeo is part of the Suez Group (NYSE:SZE).

JEA is the eighth largest municipal electric utility in the United States providing electric, water and sewer services to more than 750,000 accounts in Northeast Florida.

Project Note

Date: March 1, 2004	Florida Smelting Company – Buffalo Avenue Jacksonville, Duval County, Florida EPA ID Number: FLN000407555

Organization:
T N & Associates, Inc.,
EPA Reg. 4 STAT Contract
Name: Greg Kowalski
Signature:

Subject: Apportionment of the JEA Municipal Wells

The attached information supports the following population apportionment for the drinking water wells within 4 miles of site. The information used to develop the following apportionment values was derived from JEA provided North Grid and South Grid municipal wells well information, United Water of Florida well information, and population totals from FDEP Drinking Water Facility Reports. Well locations were derived from geographic coordinates and FDEP provided topographic map. Discrepancies were observed between FDEP and JEA information including omitted UWF wells (Lake Forrest and Magnolia Gardens), the number of wells in the South grid, and the populations served. In areas where discrepancies were observed a review of historical information was also considered and a best professional judgment was made for apportionment determinations.

The following **JEA water plants** were identified within 4 miles of site:

North Grid - Main St (9 wells), McDuff (8 wells), and Norwood (4 wells)
North Grid – 47 wells (10 plants) serve a total of 420,989 people, averaging **8,957 people per well.**

South Grid – **River Oaks (7 wells), Hendricks (5 wells), Arlington (4 wells), and Lake Lucina (3).**
South Grid – 45 wells (23 plants) serve a total of 396,461 people, averaging **8,810 people per well.**

The following **independent or historical UWF plants** were identified within 4 miles:
Woodmere – 3 wells serve a total of 4,565 people, averaging **1,522 people per well.**
Lake Forrest – 1 well serving 840 connections multiplied 2.51 people/household is **2,108 people.**
Magnolia Gardens – 1 well serving 701 connections multiplied by 2.51 equals **1,760 people.**
Jacksonville Univ. – 3 wells serving 848 people, averaging **283 people per well.**

The following page lists the apportioned groundwater target populations per radial distance from site.

RESPONSE REQUIRED
(x) None ( ) Phone call ( ) Memo ( ) Letter ( ) Report

cc: (x) File ( ) Project Manager ( ) Principal Investigator ( ) Other (specify)

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ZIP	PHONE	OWNER	OWNER TYPE	POP SERVED	DESIGN CAP	SRVC CONNEC	#PLANTS	
32233	9042475887	CITY OF ATLA	INVESTOR	10936	2120000	2200	2	
32210	9047713974	WALLACE AN	INVESTOR	200	28800	78	1	
32221	9047833294	MR. GLENN T	INVESTOR	105	22570	43	1	
32216	9047371677	DANIEL MEM	INVESTOR	150	57600	16	1	
32211	9047211257	1ST COAST F	INVESTOR	475	48696	190	1	
32221	9047832460	AUGUST PAR	INVESTOR	502	99000	201	1	
32250	9042476216	CITY OF JACK	MUNICIPALIT	20267	4737600	9404	2	
32233	9042475830	CITY OF ATLA	MUNICIPALIT	14390	6070000	4662	2	
32221	9047810876	COLE CONST	INVESTOR	120	60000	48	1	
32234	9042669055	CITY OF BALD	MUNICIPALIT	1540	1200000	650	1	
32266	9042702419	CITY OF NEPT	MUNICIPALIT	7500	2800000	3446	1	
32230	9047726080	MRS. JUSTISS	INVESTOR	200	10940	63	1	
32228	9046300905	JEA WATER &	MUNICIPALIT	2270	192000	548	1	
32225	9046656248	JEA WATER &	MUNICIPALIT	420989	119126400	140280	2161327	JEA North Grid
32225	9046654553	JEA WATER &	MUNICIPALIT	396461	138207460	113274	2161328	JEA South Grid

CNTY	PWS ID	TYPE	SOURCE	MAILING NAME	STREET	CITY	STATE
16	2160125	COMMUNITY	GROUND	ATL BCH: BUCCANEER WS	1200 SANDPIP	ATLANTIC BEACH	FL
16	2160198	COMMUNITY	GROUND	GRAZING MEADOWS/CIRCLE	9539 103RD S	JACKSONVILLE	FL
16	2160223	COMMUNITY	GROUND	TAYLORS MHP	3522 COLJEA	JACKSONVILLE	FL
16	2160254	COMMUNITY	GROUND	DANIEL MEMORIAL	3725 BELFOR	JACKSONVILLE	FL
16	2160386	COMMUNITY	GROUND	SPANISH OAK APARTMENTS	7557 ARLINGT	JACKSONVILLE	FL
16	2160390	COMMUNITY		CRYSTAL SPRINGS ESTATE	500 SOUTH C	JACKSONVILLE	FL
16	2160563	COMMUNITY	GROUND	JACKSONVILLE BEACH WTP	2500 PULLIAN	JACKSONVILLE	FL
16	2160200	COMMUNITY	GROUND	ATLANTIC BEACH WATER SY	485 11TH STR	ATLANTIC BEACH	FL
16	2160442	COMMUNITY	GROUND	COLE'S MHP	10700 NORMA	JACKSONVILLE	FL
16	2160053	COMMUNITY	GROUND	BALDWIN WATER SYSTEM	10 US 90 WES	BALDWIN	FL
16	2160206	COMMUNITY	GROUND	NEPTUNE BEACH	1019 5TH AVE	NEPTUNE BEACH	FL
16	2160601	COMMUNITY	GROUND	JUSTISS TRAILER PARK	6414 YUKON	JACKSONVILLE	FL
16	2160735	COMMUNITY	GROUND	JEA: MAYPORT WTP	1459 JULIA ST	JACKSONVILLE	FL
16	2161327	COMMUNITY	GROUND	JEA: NORTH GRID	21 WEST CHU	JACKSONVILLE	FL
16	2161328	COMMUNITY	GROUND	JEA: SOUTH GRID	102 N. KERNA	JACKSONVILLE	FL

Attach to
Pg 4 Here

Attach To 9.1 Here

ZIP	PHONE	OWNER	OWNER TYPE	POP SERVED	DESIGN CAP	SRVC CONNEC	#PLANTS
32219	9047687982	CURLY, INCO	INVESTOR	90	12000	36	1
32202	9043509824	NEIGHBORHO	INVESTOR/LIC	626	158400	343	1
32212	9047786065	DEPARTMENT	INVESTOR/LIC	1000	648000	204	1
32277	9047431888	FLORIDA WAT	INVESTOR/LIC	4565	2400000	1868	1
32210	9047252865	JEA WATER &	INVESTOR/LIC	1571	300000	449	1
32211	9047443950	JACKSONVILL	INVESTOR/LIC	848	1728000	37	1
32225	9042736926	FLORIDA WAT	INVESTOR/LIC	9302	2760000	4181	2
32221	9047810474	MR. GLEN NA	INVESTOR	165	21600	66	1
32236	9047819658	NORMANDY V	INVESTOR	4182	600000	1195	1
32218	9047575858	MR. WILLIAM	INVESTOR	96	1200	53	1
32210	9047715034	MR. ROBERT	INVESTOR	140	56000	56	2
32073	9047037297	MR. BRYAN S	INVESTOR	75	21600	30	1
32219	9047646906	MR. DON HAL	INVESTOR	137	36000	73	1
32233	9043562705	C.M.H. PARKS	INVESTOR	425	228606	248	1
32219	9047650271	MR. JERRY W	INVESTOR	177	30000	71	1
32221		WARD'S MOBI	INVESTOR	48	15980	19	1
32210	9047713811	PAUL & JAN	INVESTOR	315	28800	90	1
32221	9047830288	BONUS INNS I	INVESTOR	147	12000	42	1
32210	9047714321	THOROUGHB	INVESTOR	252	63980	101	1
32210	9047246045	MR. JAMES C.	INVESTOR	40	1800	16	1
32217	9042688555	SENTRY MAN	INVESTOR	60	36000	17	1
32219	9047647111	FLORIDA DEP	INVESTOR	25	33120	1	1
32210	9047713811	ROYAL COUR	INVESTOR	315	28800	90	1
32226	9046654553	JEA: WATER	INVESTOR	293	142512	83	1
32221	9047813377	BAILEY'S MHP	INVESTOR	75	67488	30	1
32246	9047244046	MR. ROBERT	INVESTOR	235	21720	94	1
32210	9045730541	JEFF & JANIC	INVESTOR	100	25920	16	1
32244	9047727072	UNIPROP	INVESTOR	783	86700	313	1
32233	9042410161	PROPERTY P	INVESTOR	100	6852	60	1
32223		MR. RODRIGO	INVESTOR	50	4200	10	1
32221	9047810441	CLAYTON HO	INVESTOR	1137	120000	455	1
32217	9047333730	BEAUCLERC	INVESTOR	265	40608	106	1
32219	9047659512	ULTIMATE INS	INVESTOR	60	15000	49	1

CNTY	PWS ID	TYPE	SOURCE	MAILING NAME	STREET	CITY	STATE
16	2161043	COMMUNITY	GROUND	SILVER DOLPHIN	11134 NEW KI	JACKSONVILLE	FL
16	2164279	COMMUNITY	GROUND	TIMBER CREEK WTP	10400 TIMBER	JACKSONVILLE	FL
16	2164003	COMMUNITY	GROUND	U.S. NAVY - YELLOW WATER	P.O. BOX 30,	JACKSONVILLE	FL
16	2161278	COMMUNITY	GROUND	FWS: WOODMERE WTP	5710 EDENFIE	JACKSONVILLE	FL
16	2160852	COMMUNITY	GROUND	JEA: ORTEGA HILLS WTP	5033 GREEN	JACKSONVILLE	FL
16	2160568	COMMUNITY	GROUND	JACKSONVILLE UNIVERSITY	2800 UNIVER	JACKSONVILLE	FL
16	2160064	COMMUNITY	GROUND	FWS: BEACON HILLS/COBBL	11478 SWEET	JACKSONVILLE	FL
16	2160788	COMMUNITY	GROUND	NAPOLI MOBILE HOME PARK	10200 NORMA	JACKSONVILLE	FL
16	2160811	COMMUNITY	GROUND	NORMANDY VILLAGE UTILIT	7800 DELARO	JACKSONVILLE	FL
16	2160824	COMMUNITY	GROUND	OAKS OF JACKSONVILLE	11325 N. MAIN	JACKSONVILLE	FL
16	2160894	COMMUNITY	GROUND	PINE VILLA MOBILE HOME P	7633 WILSON	JACKSONVILLE	FL
16	2160654	COMMUNITY	GROUND	STUDY ESTATES MHP	8167 OLD KIN	JACKSONVILLE	FL
16	2161022	COMMUNITY	GROUND	SHADY OAKS MHP	8654 NEW KIN	JACKSONVILLE	FL
16	2161276	COMMUNITY	GROUND	OAKS OF ATLANTIC BEACH	1020 SISTRUN	ATLANTIC BEACH	FL
16	2161192	COMMUNITY	GROUND	TROUT RIVER MOBILE HOME	5809 TROUT	JACKSONVILLE	FL
16	2161231	COMMUNITY	GROUND	WARD'S MOBILE HOME PAR	1561 HAMMO	JACKSONVILLE	FL
16	2161232	COMMUNITY	GROUND	ROYAL COURT MHP #1	5470 TIMUQU	JACKSONVILLE	FL
16	2161333	COMMUNITY	GROUND	BLAIR ROAD APARTMENTS	1535 BLAIR R	JACKSONVILLE	FL
16	2164195	COMMUNITY	GROUND	COLONIAL VILLAGE APART	9500 103RD S	JACKSONVILLE	FL
16	2164396	COMMUNITY	GROUND	GROFF APARTMENTS	5147 TIMUQU	JACKSONVILLE	FL
16	2164400	COMMUNITY	GROUND	BELLE OAKS WTP	10754 SCOTT	JACKSONVILLE	FL
16	2164401	COMMUNITY	GROUND	DINSMORE COMMUNITY CO	13190 OLD KI	JACKSONVILLE	FL
16	2164416	COMMUNITY	GROUND	ROYAL COURT MHP #2	5470 TIMUQU	JACKSONVILLE	FL
16	2164443	COMMUNITY	GROUND	JEA: WHITE SHELL BAY	9170 MILTON	JACKSONVILLE	FL
16	2164494	COMMUNITY	GROUND	BAILEY'S MHP (NORTH)	12401 NORMA	JACKSONVILLE	FL
16	2160906	COMMUNITY	GROUND	LEON MHP	1700 LEON R	JACKSONVILLE	FL
16	2160115	COMMUNITY	GROUND	BROTHERS CONCEPT 2	5353 110TH S	JACKSONVILLE	FL
16	2160025	COMMUNITY	GROUND	COUNTRY ROADS MHP	6539 TOWNSE	JACKSONVILLE	FL
16	2160006	COMMUNITY	GROUND	A & M TRAILER PARK	2051 MAYPOR	ATLANTIC BEACH	FL
16	2161337	COMMUNITY	GROUND	BARCELONA APARTMENTS	8400 BARCEL	JACKSONVILLE	FL
16	2160646	COMMUNITY	GROUND	LAMPLIGHTER MOBILE HOM	9101 NORMAN	JACKSONVILLE	FL
16	2160065	COMMUNITY	GROUND	BEAUCLERC BAY APARTME	9047 SAN JOS	JACKSONVILLE	FL
16	2160110	COMMUNITY	GROUND	BRIARWOOD ESTATES MHP	8406 NEW KIN	JACKSONVILLE	FL

Attach To Pg. 2 Here

United Water Florida (UWF):

PLANT	Well #	WQ#	ADDRESS	LAT (N) ***	LONG (W) ***	CASING DIA (IN) ***	TOTAL DEPTH(FT) ***	PUMPAGE GPM ***	# CONNECTIONS*
San Jose	1		7128 Balboa Road **	301445	813720	8	1312	1100	
	2		7128 Balboa Road **	301449	813723	16	1066	2800	4383
	3		7128 Balboa Road **	301446	813718	20	1300	2850	
Royal Lakes	1		8509 Western Way **	301244	813331	12	1170	1400	
	2		8509 Western Way **	301244	813333	12	1100	1700	2696
	3		6195 Lake Lugano Drive **	301244	813344	20	1200	2000	
Lake Forest	1			302339	814042	8	1101	900	840
Magnolia Gardens	1			302244	814215	8	1047	809	701
Arlington	1			302046	813555	8	1000	1100	
	2			302053	813510	8	1203	1200	
	3			302105	813404	10	1301	1500	6925
	4			302203	813614	8	1025	1400	
	5			301959	813417	8	1150	700	
	6			301956	813420	8	1150	1200	
Monnument Road	1		1258 Monument Road ****						
	2		1258 Monument Road ****						
Queen Akers	1		758 St. Johns Bluff ****						
Hyde Grove	1			301718	814529	8			359
Jacksonvile Heights	1			301523	814437	10	1203	1200	
	2			301445	814613	8	500	100	3671
	3			301423	814605	10	1149	1200	
Forest Brook	1			301433	814404	6	672	300	191
Venetia Terrace	1			301415	814300	6	833	500	245
Ortega Hills	1			301306	814239	10	956	270	449
	2			301304	814239	10	800	680	

* Fax received from Gordon Grimes (UWF) 7/10/01.
** Phone conversation with Tom Griffis (UWF) and Sandra Dowling (Dynamac) 7/10/01.
*** Fax received from April Roughton (St. John's River Water Management District) 7/16/01.
**** Phone conversation with T. Griffis (UWF) and P. Taylor (Weston) 7/17/01.

wells

Jul-98

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT		WQ#	USGS D#	RESD J#	CUP #		ADDRESS	QUAD MAP	SEC	TWNP	RANGE
ARGYLE	1	0901		1151	2-031-0084	?	8358 CANDLEWOOD DR W	JAX HEIGHTS	34	03S	25E
	2	0902		2804	2-031-0084	?	8540 BISHOPWOOD DR	JAX HEIGHTS	34	03S	25E
FAIRFAX	3	0301	162	226	2-031-0084	G	2501 PULLMAN ST	JACKSONVILLE	03	02S	26E
	4	0302	168	232	2-031-0084	J	1601 W 20TH ST	JACKSONVILLE	03	02S	26E
	5	0303	240	307	2-031-0084	F	1977 W 20TH ST	JACKSONVILLE	03	02S	26E
	6	0304	52A	116	2-031-0084	D	1801 W 20TH ST	JACKSONVILLE	03	02S	26E
	7	0305	46A	110	2-031-0084	C	3510 FAIRFAX ST	JACKSONVILLE	03	02S	26E
	8	0306	82	156	2-031-0084	H	1995 W 24TH ST	JACKSONVILLE	03	02S	26E
	9	0307	99	163	2-031-0084	E	1589 W 24TH ST	JACKSONVILLE	03	02S	26E
	10	0308	100	164	2-031-0084	I	2409 FAIRFAX ST	JACKSONVILLE	03	02S	26E
HIGHLANDS	11	0601	330	395	2-031-0084	AL	DEPAUL DR & I-95	TROUT RIVER	49	01S	26E
	12	0602	329	394	2-031-0084	AK	801 BECKNER AVE	TROUT RIVER	49	01S	26E
	13	0603	226	293	2-031-0084	AO	10216 MONACO DR	TROUT RIVER	13	01S	26E
	14	0604	227	294	2-031-0084	AN	10402 MONACO DR	TROUT RIVER	49	01S	26E
	15	0605		5846	2-031-0084	AM	10610 MONACO DR	TROUT RIVER	49	01S	26E
LAKESHORE	16	0501	333	398	2-031-0084	AD	4543 SUNDERLAND RD	JACKSONVILLE	59	02S	26E
	17	0502	103	167	2-031-0084	AG	2113 HAMILTON ST	JACKSONVILLE	59	02S	26E
	18	0503	96	160	2-031-0084	AC	4594 APPLETON AVE	JACKSONVILLE	59	02S	26E
	19	0504	98	162	2-031-0084	AE	2464 HAMILTON ST	JACKSONVILLE	59	02S	26E
	20	0505	735	15	2-031-0084	AB	4565 SAN JUAN AVE	JACKSONVILLE	59	02S	26E

Jul-98

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
ARGYLE	0901	301655.8	814323.4	1976	16X10	600	900	1000
	0902	301829.7	814221.1	1981	16X10	607	900	1000
FAIRFAX	0301	302131	814058	1971	18X12	519	1309	2500
	0302	301931.5	814654.1	1972	12	498	1320	2000
	0303	301423.8	814634.3	1972	18X12	544	1362	2000
	0304	301143.7	814536.8	1941	10	513	1356	1000
	0305	302122.7	814112.4	1963	10	530	1280	1500
	0306	301647.1	814319.1	1950	12		1300	1400
	0307	301841.4	814220.6	1950	12	502	1338	1400
	0308	302133.9	814112.3	1949	12		1365	900
HIGHLANDS	0601	302525.7	813712.1	1968	20	583	1211	2500
	0602	302103.5	813752.8	1968	20	545	1209	2500
	0603	302802.9	813422.4	1972	18X12	560	1296	2500
	0604	302801.2	813422.8	1972	18X12	570	1257	2500
	0605	302012	813847.6	1989	18	570	1235	2500
LAKESHORE	0501	301842.8	814237.4	1950	12	472	1318	2000
	0502	301841.1	814220.7	1950	12	535	1332	2000
	0503	301852.7	814234.2	1950	12	539	1319	2000
	0504	301837.8	814225.3	1962	12	525	1332	2400
	0505	301907	814209.3	1976	18	555	1259	2000

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	USGS D#	RESD. J#	CUP #	ADDRESS	QUAD MAP	SEC	TWNP	RANGE
MAIN ST	21 0101	170	234	2-031-0084 S	331 PHELPS ST	JACKSONVILLE	37	02S	26E
	22 0102	180A	244	2-031-0084 R	997 MAIN ST	JACKSONVILLE	37	02S	26E
	23 0103	175	239	2-031-0084 O	1077 LAURA ST	JACKSONVILLE	37	02S	26E
	24 0104	19A	83	2-031-0084 T	820 IONIA ST	JACKSONVILLE	13	02S	26E
	25 0105	335	400	2-031-0084 Q	1150 CLARK ST	JACKSONVILLE	37	02S	26E
	26 0106								
	27 0107	239	308	2-031-0084 M	1600 BOULEVARD ST	JACKSONVILLE	37	02S	26E
	28 0108	171A	235	2-031-0084 N	979 MARKET ST	JACKSONVILLE	37	02S	26E
	29 0119	1786	1817	2-031-0084 L	204 W 3RD ST	JACKSONVILLE	37	02S	26E
	30 0120	1787	1818	2-031-0084 K	302 W 4TH ST	JACKSONVILLE	37	02S	26E
MARIETTA	31 0701	867	963	2-031-0084 BH	201 MCCARGO ST N	MARIETTA	15	02S	25E
	32 0702	866	964	2-031-0084 BI	58 GREENLAND AVE N	MARIETTA	15	02S	25E
	33 0703	2283	2256	2-031-0084 BG	8134 OKLAHOMA ST	MARIETTA	15	02S	25E
	34 0704	2223	2257	2-031-0084 BE	260 JACKSON AVE	MARIETTA	15	02S	25E
MCDUFF	35 0201	332A	397	2-031-0084 W	3151 PLUM ST	JACKSONVILLE	21	02S	26E
	36 0202	241	308	2-031-0084 Z	2900 ROSSELLE ST	JACKSONVILLE	21	02S	26E
	37 0203	195	259	2-031-0084 V	3047 RANDALL ST	JACKSONVILLE	21	02S	26E
	38 0204	59A	123	2-031-0084 X	1036 DAY AVE	JACKSONVILLE	21	02S	26E
	39 0205	101	165	2-031-0084 AA	1218 DAY AVE	JACKSONVILLE	21	02S	26E
	40 0206	50A	114	2-031-0084 Y	3001 RANDALL ST	JACKSONVILLE	21	02S	26E
NORWOOD	41 0401	261	328	2-031-0084 AU	1014 CRESTWOOD ST	JACKSONVILLE	37	01S	26E
	42 0402	336	401	2-031-0084 AT	1025 KENMORE ST	TROUT RIVER	37	01S	26E
	43 0403	271	336	2-031-0084 A	1231 CRESTWOOD ST	JACKSONVILLE	37	01S	26E
	44 0404	863	919	2-031-0084 AV	713 CARLTON ST	TROUT RIVER	37	01S	26E

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
MAIN ST	0101	302036.1	813943.1	1949	12	501	1276	1600
	0102	302009.7	813923.9	1971	12	531	1319	2200
	0103	302526	813702.5	1971	18X12	520	1282	3000
	0104	302019.2	813928.3	1968	12	514	1302	2000
	0105	302004.7	813919.6	1949	12	531	1286	1900
	0107	302534.9	813929.7	1972	18X12	514	1303	2000
	0108	302010.3	813923.4	1922	10		1248	1550
	0119	302227.4	814008.7	1944	18	532	1284	2800
	0120	302801.1	813423.7	1977	18	530	1282	2800
MARIETTA	0701	301423.3	814653.3	1975	18	537	1225	2500
	0702	301626	814320.2	1975	18	523	1228	2900
	0703	301145.8	814541.2	1980	18	548	1250	2500
	0704	301423.3	814636.7	1980	18	553	1315	2500
MCDUFF	0201	302120.7	814112.3	1972	18X12	570	1234	2500
	0202	302130.8	814128.5	1972	18X12	594	1324	3000
	0203	302107.4	814110.8	1941	12		1300	1500
	0204	302121	814126	1941	12		1260	1900
	0205	302109.6	814123.5	1949	12		1320	2000
	0206	302120.7	814059.4	1947	12	540	1303	2000
NORWOOD	0401	302536.7	813937.9	1951	12	540	1341	2250
	0402	302527.4	813937.3	1951	12	520	1303	2250
	0403	302536.3	813926.4	1951	12	543	1235	2250
	0404	302515	813937.8	1976	18	554	1200	2700

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT		WQ#	USGS D#	RESD J#	CUP #		ADDRESS	QUAD MAP	SEC	TWNP	RANGE
SOUTHWEST	45	0801	2495	2950	2-031-0084	BA	7754 WHEAT RD	JAX HEIGHTS	14	03S	25E
	46	0802	2497	2961	2-031-0084	BB	5847 ROVER DR	JAX HEIGHTS	14	03S	25E
	47	0803	2494	2949	2-031-0084	AZ	7971 BLANK DR N	JAX HEIGHTS	14	03S	25E

Jul-98

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
NORTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
SOUTHWEST	0801	301647.7	814325.9	1982	18X18	446	1180	3000
	0802	301647.2	814317.8	1982	18X17	473	1162	3000
	0803	301640.7	814325.2	1982	18X18	484	1240	3000

Jul-98 JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SOUTH GRID WATER TREATMENT FACILITIES

PLANT		WQ#	USGS D#	RESD J#	CUP #		ADDRESS	QUAD MAP	SEC	TWNP	RANGE
ARBOR PT	48	N101			2-031-0076	A	255 JOEANDY RD	JAX BEACH	38	02S	28E
ARLINGTON	49	5402	479	546	2-031-0076	E	1415 SPRINKLE DR	ARLINGTON	52	02S	27E
	50	5403	857	64	2-031-0076	F	1412 WHITLOCK AVE	ARLINGTON	52	02S	27E
	51	5404	673	790	2-031-0076	G	1595 MAITLAND AVE	ARLINGTON	52	02S	27E
	52	5405		5845	2-031-0076	H	1660 SPRINKLE DR	ARLINGTON	52	02S	27E
COMMUNITY HALL	53	M501		1888	2-031-0076	K	2935 ORANGEPICKER RD (E)	ORANGE PARK	40	04S	27E
	54	M502		3596	2-031-0076	L	2935 ORANGEPICKER RD (S)	ORANGE PARK	40	04S	27E
	55	M503		4123	2-031-0076	M	2935 ORANGEPICKER RD (W)	ORANGE PARK	40	04S	27E
	56	M504			2-031-0076	N	2738 -WP01 ORANGEPICKER RD	ORANGE PARK	40	04S	27E
DEERWOOD 1	57	5601		473	2-031-0076	O	8402 HOLLYRIDGE RD	BAYARD	25	03S	27E
	58	5602	3832	3821	2-031-0076	P	8490 HOLLYRIDGE RD	BAYARD	25	03S	27E
DEERWOOD 3	59	5701	3831		2-031-0076	Q	7587 SOUTHSIDE BLVD	BAYARD	13	03S	27E
	60	5702			2-031-0076	R	7603-WP01 SOUTHSIDE BLVD	BAYARD	13	03S	27E
	61	5703			2-031-0076	S	7603-WP02 SOUTHSIDE BLVD	BAYARD	13	03S	27E
HENDRICKS	62	5001	237	304	2-031-0076	U	1601 LASALLE ST	JACKSONVILLE	44	02S	26E
	63	5002	198	262	2-031-0076	V	1457 NALDO AVE	JACKSONVILLE	44	02S	26E
	64	5003	53A	117	2-031-0076	W	1433 LARUE ST	JACKSONVILLE	44	02S	26E
	65	5501	2885	2960	2-031-0076	Y	2081 REED AVE	JACKSONVILLE	45	02S	26E
	66	5502	2884	2959	2-031-0076	X	952 BROADCAST PLACE	JACKSONVILLE	44	02S	26E
RIDENOUR	67	5901					102 N. Kernan Blvd				
	68	5902					102 N. Kernan Blvd				
	69	5903					102 N. Kernan Blvd				

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SOUTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
ARBOR PT	N101	301841.2	813914.3	1984	16X12	409	835	1600
ARLINGTON	5402	301742	813051.4	1973	18x12	606	1350	2000
	5403	301423.8	814634.3	1975	18	569	1105	1600
	5404	302131	814058	1975	18	578	814	3000
	5405	301647.1	814319.1	1989	18	613	1117	2500
COMMUNITY HALL	M501	302801.1	813423.7	1978	12X8	460	624	1000
	M502	302227.4	814008.7	1984	12X8	460	900	1000
	M503	302534.9	813929.7	1985	16	485	1225	2500
	M504	302010.3	813923.4	1994	18	473	1225	2500
DEERWOOD 1	5601	302526	813702.5	1973	12X8	500	1014	1000
	5602	301840.1	813933.8	1984	16X12	523	1000	2000
DEERWOOD 3	5701	301832.5	813909.2	1984	16X12	555	980	2000
	5702	301846.5	813902.8	1994	18	583	1198	2500
	5703	301818.8	813900.6	1994	18	573	1180	2500
HENDRICKS	5001	302025.5	813935.1	1972	18X12	549	1291	2500
	5002	302107.4	814110.8	1971	18X12	552	1297	2500
	5003	302120.7	814112.3	1959	10	510	1286	1500
	5501	302120.7	814059.4	1982	18X16	538	1270	1700
	5502	302121	814126	1982	18X16	528	1252	1700
RIDENOUR	5901	301935	812945	1998	18		900	2500
	5902	301933	812935	1998	18		900	2500
	5903	301749.5	813833.2	1997	18		920	2500

Jul-98 JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SOUTH GRID WATER TREATMENT FACILITIES

PLANT		WQ#	USGS D#	RESD J#	CUP #	ADDRESS	QUAD MAP	SEC	TWNP	RANGE
LOVEGROVE	70	5201	275	340	2-031-0076 AB	3114 UNIVERSITY BLVD S	ARLINGTON	52	02S	27E
	71	5202	225	292	2-031-0076 AC	5575 BARKER ST	ARLINGTON	52	02S	27E
	72	5203	649	27	2-031-0076 AD	2801 UNIVERSITY BLVD S	ARLINGTON	52	02S	27E
	73	5204	2193	2381	2-031-0076 AE	5426 WILMAN WAY	ARLINGTON	52	02S	27E
OAKRIDGE	74	5301	223	290	2-031-0076 AJ	11789 SAINTS RD	ARLINGTON	29	02S	28E
	75	5302	224	291	2-031-0076 AK	11760 SAINTS RD	ARLINGTON	29	02S	28E
	76	5303	665	801	2-031-0076 AL	11770 ALDEN RD	ARLINGTON	29	02S	28E
	77	5304	650	26	2-031-0076 AM	3005 SNAPPER ST	ARLINGTON	32	02S	28E
	78	5305	3825	5847	2-031-0076 AN	11999 SAINTS RD	ARLINGTON	29	02S	28E
PICKWICK	79	M101		601	2-031-0076 AP	3316 PICKWICK DR S	ORANGE PARK	31	03S	27E
	80	M102		1889	2-031-0076 AQ	3316 PICKWICK DR S	ORANGE PARK	31	03S	27E
	81	M103		2775	2-031-0076 AR	3316 PICKWICK DR S	ORANGE PARK	31	03S	27E
	82	M104		4382	2-031-0076 AS	3316 PICKWICK DR S	ORANGE PARK	31	03S	27E
	83	M105	538	605	2-031-0076 J	3054 SHADY DR	ORANGE PARK	40	03S	27E
RIVEROAKS	84	5101	334	399	2-031-0076 AT	3016 OLD ST AUGUSTINE RD	JACKSONVILLE	44	02S	27E
	85	5102	95	259	2-031-0076 AU	2560 SUMMERALL AVE	JACKSONVILLE	45	02S	26E
	86	5104	54A	118	2-031-0076 AV	1845 RIVER OAKS BLVD	JACKSONVILLE	47	02S	26E
	87	5105	105	169	2-031-0076 AW	1576 MARCO PL (SW CORNER)	JACKSONVILLE	47	02S	26E
	88	5107	1098	172	2-031-0076 AX	1636 MARCO PL (NE CORNER)	JACKSONVILLE	46	02S	26E
	89	5108	643	1	2-031-0076 AY	1621 ALFORD PL	JACKSONVILLE	46	02S	26E
	90	5110	3654	1819	2-031-0076 AZ	2782 SOUTHWOOD LN	JACKSONVILLE	47	02S	26E
SOUTHEAST	91	5801			2-031-0076 BD	13570 W. M. DAVIS PARKWAY	JAX BEACH	12	03S	28E
	92	5802			2-031-0076 BE	13570 W. M. DAVIS PARKWAY	JAX BEACH	12	03S	28E
SUNNI PINES	93	N301			2-031-0076 BB	2400 SAN PABLO RD	JAX BEACH	25	02S	28E
	94	N302			2-031-0076 BC	2400 SAN PABLO RD	JAX BEACH	38	02S	28E

JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SOUTH GRID WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
LOVEGROVE	5201	301209.1	813733.8	1957	18X12	515	1234	2500
	5202	301838.2	813921.2	1972	18X12	547	1277	2500
	5203	301840.1	813933.8	1975	18	534	1005	1400
	5204	300858.2	813804.5	1979	18	549	1301	2800
OAKRIDGE	5301	301742.8	813050.4	1970	18X12	420	1125	2500
	5302	301742.6	813034.6	1970	18X12	423	1179	2500
	5303	301800.2	813051.6	1975	18	422	1185	Monitor well
	5304	301807.4	813840.6	1975	18	424	1276	2200
	5305	301748.7	813847.2	1989	18	440	1093	2500
PICKWICK	M101	302802.9	813422.4	1963	8	454	1000	1000
	M102	301810.2	812704.6	1978	12X8	460	680	850
	M103	301549	812713.8	1981	12X8	454	700	1000
	M104	301409.7	813304.2	1986	12X8	446	1004	1000
	M105	301931.5	814654.1	1974	18X12	484	1000	1500
RIVEROAKS	5101	301316.4	813524	1955	18X12	535	1500	Plugged
	5102	301300.1	813228.5	1950	12	515	1343	1900
	5104	301411.1	813305.8	1949	10	504	1348	500
	5105	302334.5	812549.2	1946	12	496	1062	700
	5107	301407	813253.1	1974	18	555	1012	1500
	5108	301928.9	812736.7	1975	18	553	1298	1500
	5110	301537.4	812711.9	1978	18	525	1288	2500
SOUTHEAST	5801	302013.5	813540.8	1995	24X18	349	870	2500
	5802	302005.7	813532.1	1995	24X18	368	893	2500
SUNNI PINES	N301	301752.3	813605.2	1974	12X8	417	782	1000
	N302	302008.1	813545.3	1989	16X12	399	837	1000

Jul-98 JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SMALL WATER TREATMENT FACILITIES

PLANT	WQ#	USGS D#	RESD J#	CUP #	ADDRESS	QUAD MAP	SEC	TWNP	RANGE
BRIERWOOD	95 1D01	536	603		8460 BRIERWOOD ROAD	BAYARD	21	03S	27E
	96 1D02		3018		8460 BRIERWOOD ROAD	BAYARD	21	03S	27E
BRIERWOOD PLAZA	97 1D03		5857		5295 BAYMEADOWS ROAD	BAYARD	22	03S	27E
DISTRICT II	98 D301		1017	2-031-0092 A	1840 CEDAR BAY RD	EASTPORT	17	01S	27E
MAYPORT	99 8A01	464A	531	2-031-0099 A	1459 ROXIE ST	MAYPORT	38	01S	29E
	100 8A03			2-031-0099 B	1459 ROXIE ST	MAYPORT	38	01S	29E
SHEFFIELD VILLAGE	101 D101				12625 MOOSE RD (NE)	EASTPORT	35	01N	27E
	102 D102				12625 MOOSE RD (SE)	EASTPORT	35	01N	27E

Jul-98 JACKSONVILLE ELECTRIC AUTHORITY, WATER AND WASTEWATER TREATMENT
SMALL WATER TREATMENT FACILITIES

PLANT	WQ#	LAT (N)	LONG (W)	YEAR DRILLED	CASING DIA (IN)	CASING DEPTH(FT)	TOTAL DEPTH(FT)	PUMPAGE GPM
BRIERWOOD	1D01	301932.7	812925.3		12X8	372	1104	1650
	1D02	301800.4	813840.7	1982	12X8	472	705	925
BRIERWOOD PLAZA	1D03	301725	813050.4	1988	12X8	441	865	500
DISTRICT II	D301	302525.7	813712.1		12X8		1000	1000
MAYPORT	8A01	301743.2	813622.8	1973	12X6	400	1200	500
	8A03	301739.8	813610.4	1994	6X4			500
SHEFFIELD	D101	302004.3	813859.3	1988	10X6	500	750	300
VILLAGE	D102	302003.2	813845.2	1988	10X6	500	750	300

Love grove

WELL NO. 1 5875 BARKER STREET		5202
WELL NO. 2 3114 UNIVERSITY BLVD	K-MART	5203
WELL NO. 3 2801 UNIVERSITY BLVD.		5201
WELL NO. 4 5426 WILMAN WAY		5204
*MAYPORT WTP 1459 ROXIE STREET	241-2852	
WELL NO. 1 1459 ROXIE STREET		8A01
WELL NO. 2 1459 ROXIE STREET		8A03
*OAKRIDGE WTP 11789 SAINTS ROAD	641-4676	
WELL NO. 1 11789 SAINTS ROAD		5301
WELL NO. 2 11760 SAINTS ROAD		5302
WELL NO. 4 3005 SNAPPER ROAD		5304
WELL NO. 5 11999 SAINTS ROAD	POWER LINES	5305
*PICKWICK WTP 3316 PICKWICK DRIVE S.	733-9438	
WELL NO. 4 3316 PICKWICK DRIVE S.		M104
WELL NO. 5 3054 SHADY DRIVE		M105
*REGENCY PLANT 9484 REGENCY SQUARE BLVD.		
WELL NO. 1 ON SITE		
WELL NO. 2 IN PARKING LOT		
WELL NO. 3 IN PARKING LOT		
*RIDENOUR WTP 102 KERNAN BLVD. N.	665-4553	
WELL NO. 1 102 KERNAN BLVD. N.		5901
WELL NO. 2 102 KERNAN BLVD. N.		5902
WELL NO. 3 102 KERNAN BLVD. N.		5903
*RIVEROAKS WTP 1851 RIVEROAKS ROAD	396-1437	
WELL NO. 1 1636 MARCO PLACE	(NORTH OF FIELD)	5105
WELL NO. 2 1636 MARCO PLACE	(SOUTH OF FIELD)	5107
WELL NO. 3 1845 RIVEROAKS BLVD.		5104
WELL NO. 4 2560 SUMMERAL STREET		5102
WELL NO. 5 2782 SOUTHWOOD LANE		5110
WELL NO. 7 1621 ALFORD PLACE		5108
*SOUTHEAST WTP 13600 W.M. DAVIS PARKWAY	992-8264	
WELL NO. 1 13600 W.M. DAVIS PARKWAY		5801
WELL NO. 2 13600 W.M. DAVIS PARKWAY		5802

PLANT AND WELL LOCATIONS NORTHSIDE

*ARGYLE WTP 8358 CANDLEWOOD DR. W. 777-1513

WELL NO. 1 8358 CANDLEWOOD DR. W. O9O1
WELL NO. 2 8540 BISHOPWOOD DR. O9O2

*CECIL FIELD (YELLOW WATER) 573-8917

WELL NO. 1
WELL NO. 2

*CECIL FIELD 361 13361 SKYMASTER ROAD 573-0361

WELL NO. 1
WELL NO. 2
WELL NO. 3

*CECIL FIELD 16 6135 AUTHORITY AVE. 573-8964

WELL NO. 4
WELL NO. 5

*DISTRIC II WTP 1840 CEDAR BAY ROAD

WELL NO 1 1840 CEDAR BAY ROAD D301

*FAIRFAX 3020 20TH & FAIRFAX 353-6588

WELL NO.1 2409 FAIRFAX & 14TH O3O8
WELL NO. 2 20TH & FAIRFAX O3O4
WELL NO. 3 1977 20TH & PULLMAN O3O3
WELL NO. 4 3510 25TH & FAIRFAX O3O5
WELL NO. 5 1995 24TH & PULLMAN O3O6
WELL NO. 6 1589 24TH & GRUTHAL O3O7
WELL NO. 7 2501 PULLMAN & 15TH O3O1
WELL NO. 8 1603 20TH & GRUNTHAL O302

*GATE MARITIME 5710 CHANNELVIEW BLVD. 751-0164

WELL NO. 1 5710 CHANNELVIEW BLVD.
WELL NO. 2 5710 CHANNELVIEW BLVD.

*HIGHLANDS WTP 801 BECKNER STREET 751-1996

WELL NO. 1 801 BECKNER ROAD O602
WELL NO. 2 IN FIELD BY I-95 O601
WELL NO. 3 10402 MONACO DRIVE (BY FOOD STORE) O603
WELL NO. 4 10216 MONACO DRIVE O604
WELL NO. 5 10610 MONACO DRIVE O605

*NORWOOD WTP	1033 ESCAMBIA STREET	764-1166	
WELL NO. 1	1033 ESCAMBIA STREET		O401
WELL NO. 2	1025 KENMORE STREET		O403
WELL NO. 3	1231 CRESTWOOD STREET		O402
WELL NO. 4	713 CARLTON STREET		O404
*ORTEGA BLANDING WTP	7703 BLANDING BLVD	778-9523	
WELL NO. 1	7703 BLANDING BLVD		
WELL NO. 2	7703 BLANDING BLVD		
*SOUTHWEST WTP	7754 WHEAT ROAD	778-4730	
WELL NO. 1	7754 WHEAT ROAD		O8O1
WELL NO. 2	5847 ROVER DRIVE		O8O2
WELL NO. 3	7971 BLANK ROAD		O8O3
WELL NO. 4	WHEAT ROAD		
*WESTLAKE WTP	CISCO RD.		
WELL NO. 1	CISCO ROAD	NOT IN SERVICE	H201
* WINGATE BOOSTER	WINGATE ROAD		
*WHITESHELL	648 MILTON ROAD	251-3692	
WELL NO.1	9170 MILTON RD.		
WELL NO.2	9170 MILTON RD.		

*ARBOR POINT WTP 255 JOE ANDY ROAD	221-0405	
WELL NO. 1 255 JOE ANDY ROAD		N101
*ARLINGTON WTP 1425 MAITLAND ROAD	744-0148	
WELL NO. 1 1415 SPRINKLE DRIVE		5402
WELL NO. 2 1595 MAITLAND AVE.		5404
WELL NO. 3 1412 WHITLOCK DRIVE		5403
WELL NO. 4 1660 SPRINKLE DRIVE		5405
*BRIERWOOD WTP 6513 POWERS AVE.	828-5474	
WELL NO. 1 6513 POWERS AVE.		6001
WELL NO. 2 6513 POWERS AVE.		6002
WELL NO. 3 6513 POWERS AVE.		6003
WELL NO. 4 6513 POWERS AVE.		6004
WELL NO. 5 6513 POWERS AVE.		6005
*COMMUNITY HALL WTP 2935 ORANGEPICKER ROAD	262-7140	
WELL NO. 1 2935 ORANGEPICKER ROAD		M501
WELL NO. 2 2935 ORANGEPICKER ROAD		M502
WELL NO. 3 2935 ORANGEPICKER ROAD		M503
WELL NO. 4 2738 ORANGEPICKER ROAD		M504
WELL NO. 5 2515 ORANGEPICKER ROAD		M505
*DEERWOOD I WTP 8402 HOLLYRIDGE ROAD	642-3998	
WELL NO. 1 8402 HOLLYRIDGE ROAD		5601
WELL NO. 2 8490 HOLLYRIDGE ROAD		5602
*DEERWOOD III 7587 SOUTHSIDE BLVD.	997-8153	
WELL NO. 1 7587 SOUTHSIDE BLVD.		5701
WELL NO. 2 7603 SOUTHSIDE BLVD.		5702
WELL NO. 3 7603 SOUTHSIDE BLVD.		5703
WELL NO. 4 7603 SOUTHSIDE BLVD.		5704
WELL NO. 5 7603 SOUTHSIDE BLVD.		5705
WELL NO. 6 7603 SOUTHSIDE BLVD.		5706
*HENDRICKS WTP 1418 KINGS ROAD	396-1399	QC NO.
WELL NO. 1 2081 REED AVE.		5501
WELL NO. 2 952 BROADCAST PLACE		5502
WELL NO. 3 1433 LA RUE AVE.		5003
WELL NO. 4 1457 NALDO STREET		5002
WELL NO. 5 1601 LA SALLE STREET		5001

PLANT AND WELL LOCATIONS SOUTHSIDE

*LOVEGROVE WTP 5575 BARKER STREET	398-1422

White Shell Bay Water Treatment Plant

1. One
2. 2 active wells
3. Zero
4. Average Daily Flow = 0.06 MGD
   Population = ADF / 350 Gallons Per Day Per Single Family Home = 171 EDUs (Equivalent Dwelling Units)
5. Stand Alone Plant
6. No
7. No
8. Plant Location : 9170 Milton Road
   Well 1 9170 Milton Road
   Well 2 9170 Milton Raod
9. Well 1
   Well 2
10. Floridan Aquifer
11. No

Regency Square Water Treatment Plant

1. One
2. 3 active wells
3. Zero
4. Average Daily Flow = 0.61 MGD
   Population = ADF / 350 Gallons Per Day Per Single Family Home = 1742 EDUs (Equivalent Dwelling Units)
5. Stand Alone Plant
6. No
7. No
8. Plant Location : 9484 Regency Square Blvd.
   Well 1 9484 Regency Square Blvd
   Well 2 9484 Regency Square Blvd
9. Well 1
   Well 2
10. Floridan Aquifer
11. No

Julington Creek Plantation Water Treatment Plant

1. One

2. 2 active wells

3. Zero

4. Average Daily Flow = 1.76 MGD
   Population = ADF / 350 Gallons Per Day Per Single Family Home = 5,208 EDUs (Equivalent Dwelling Units)

5. Stand Alone Plant – Soon to be gridded with the JEA South Grid System

6. No

7. Yes

8. Plant Location : 628 Flora Branch Road
   Well 1 628 Flora Branch Road
   Well 2 628 Flora Branch Road

9. Well 1
   Well 2

10. Floridan Aquifer

11. No

Reference 20

CNTY	PWS ID	TYPE	SOURCE	MAILING NAME	STREET	CITY	STATE
16	2161043	COMMUNITY	GROUND	SILVER DOLPHIN	11134 NEW KI	JACKSONVILLE	FL
16	2164279	COMMUNITY	GROUND	TIMBER CREEK WTP	10400 TIMBER	JACKSONVILLE	FL
16	2164003	COMMUNITY	GROUND	U.S. NAVY - YELLOW WATER	P.O. BOX 30,	JACKSONVILLE	FL
16	2161278	COMMUNITY	GROUND	FWS: WOODMERE WTP	5710 EDENFIE	JACKSONVILLE	FL
16	2160852	COMMUNITY	GROUND	JEA: ORTEGA HILLS WTP	5033 GREEN	JACKSONVILLE	FL
16	2160568	COMMUNITY	GROUND	JACKSONVILLE UNIVERSITY	2800 UNIVER	JACKSONVILLE	FL
16	2160064	COMMUNITY	GROUND	FWS: BEACON HILLS/COBBL	11478 SWEET	JACKSONVILLE	FL
16	2160788	COMMUNITY	GROUND	NAPOLI MOBILE HOME PARK	10200 NORMA	JACKSONVILLE	FL
16	2160811	COMMUNITY	GROUND	NORMANDY VILLAGE UTILIT	7800 DELARO	JACKSONVILLE	FL
16	2160824	COMMUNITY	GROUND	OAKS OF JACKSONVILLE	11325 N. MAIN	JACKSONVILLE	FL
16	2160894	COMMUNITY	GROUND	PINE VILLA MOBILE HOME P	7633 WILSON	JACKSONVILLE	FL
16	2160654	COMMUNITY	GROUND	STUDY ESTATES MHP	8167 OLD KIN	JACKSONVILLE	FL
16	2161022	COMMUNITY	GROUND	SHADY OAKS MHP	8654 NEW KIN	JACKSONVILLE	FL
16	2161276	COMMUNITY	GROUND	OAKS OF ATLANTIC BEACH	1020 SISTRUN	ATLANTIC BEACH	FL
16	2161192	COMMUNITY	GROUND	TROUT RIVER MOBILE HOME	5809 TROUT	JACKSONVILLE	FL
16	2161231	COMMUNITY	GROUND	WARD'S MOBILE HOME PAR	1561 HAMMO	JACKSONVILLE	FL
16	2161232	COMMUNITY	GROUND	ROYAL COURT MHP #1	5470 TIMUQU	JACKSONVILLE	FL
16	2161333	COMMUNITY	GROUND	BLAIR ROAD APARTMENTS	1535 BLAIR R	JACKSONVILLE	FL
16	2164195	COMMUNITY	GROUND	COLONIAL VILLAGE APART	9500 103RD S	JACKSONVILLE	FL
16	2164396	COMMUNITY	GROUND	GROFF APARTMENTS	5147 TIMUQU	JACKSONVILLE	FL
16	2164400	COMMUNITY	GROUND	BELLE OAKS WTP	10754 SCOTT	JACKSONVILLE	FL
16	2164401	COMMUNITY	GROUND	DINSMORE COMMUNITY CO	13190 OLD KI	JACKSONVILLE	FL
16	2164416	COMMUNITY	GROUND	ROYAL COURT MHP #2	5470 TIMUQU	JACKSONVILLE	FL
16	2164443	COMMUNITY	GROUND	JEA: WHITE SHELL BAY	9170 MILTON	JACKSONVILLE	FL
16	2164494	COMMUNITY	GROUND	BAILEY'S MHP (NORTH)	12401 NORMA	JACKSONVILLE	FL
16	2160906	COMMUNITY	GROUND	LEON MHP	1700 LEON R	JACKSONVILLE	FL
16	2160115	COMMUNITY	GROUND	BROTHERS CONCEPT 2	5353 110TH S	JACKSONVILLE	FL
16	2160025	COMMUNITY	GROUND	COUNTRY ROADS MHP	6539 TOWNSE	JACKSONVILLE	FL
16	2160006	COMMUNITY	GROUND	A & M TRAILER PARK	2051 MAYPOR	ATLANTIC BEACH	FL
16	2161337	COMMUNITY	GROUND	BARCELONA APARTMENTS	8400 BARCEL	JACKSONVILLE	FL
16	2160646	COMMUNITY	GROUND	LAMPLIGHTER MOBILE HOM	9101 NORMAN	JACKSONVILLE	FL
16	2160065	COMMUNITY	GROUND	BEAUCLERC BAY APARTME	9047 SAN JOS	JACKSONVILLE	FL
16	2160110	COMMUNITY	GROUND	BRIARWOOD ESTATES MHP	8406 NEW KIN	JACKSONVILLE	FL

ATTACH TO Pg. 2 HERE

ZIP	PHONE	OWNER	OWNER TYPE	POP SERVED	DESIGN CAP	SRVC CONNEC	#PLANTS
32219	9047687982	CURLY, INCO	INVESTOR	90	12000	36	1
32202	9043509824	NEIGHBORHO	INVESTOR/LIC	626	158400	343	1
32212	9047786065	DEPARTMENT	INVESTOR/LIC	1000	648000	204	1
32277	9047431888	FLORIDA WAT	INVESTOR/LIC	4565	2400000	1868	1
32210	9047252865	JEA WATER &	INVESTOR/LIC	1571	300000	449	1
32211	9047443950	JACKSONVILL	INVESTOR/LIC	848	1728000	37	1
32225	9042736926	FLORIDA WAT	INVESTOR/LIC	9302	2760000	4181	2
32221	9047810474	MR. GLEN NA	INVESTOR	165	21600	66	1
32236	9047819658	NORMANDY V	INVESTOR	4182	600000	1195	1
32218	9047575858	MR. WILLIAM	INVESTOR	96	1200	53	1
32210	9047715034	MR. ROBERT	INVESTOR	140	56000	56	2
32073	9047037297	MR. BRYAN S	INVESTOR	75	21600	30	1
32219	9047646906	MR. DON HAL	INVESTOR	137	36000	73	1
32233	9043562705	C.M.H. PARKS	INVESTOR	425	228606	248	1
32219	9047650271	MR. JERRY W	INVESTOR	177	30000	71	1
32221		WARD'S MOBI	INVESTOR	48	15980	19	1
32210	9047713811	PAUL & JAN	INVESTOR	315	28800	90	1
32221	9047830288	BONUS INNS I	INVESTOR	147	12000	42	1
32210	9047714321	THOROUGHB	INVESTOR	252	63980	101	1
32210	9047246045	MR. JAMES C.	INVESTOR	40	1800	16	1
32217	9042688555	SENTRY MAN	INVESTOR	60	36000	17	1
32219	9047647111	FLORIDA DEP	INVESTOR	25	33120	1	1
32210	9047713811	ROYAL COUR	INVESTOR	315	28800	90	1
32226	9046654553	JEA: WATER	INVESTOR	293	142512	83	1
32221	9047813377	BAILEY'S MHP	INVESTOR	75	67488	30	1
32246	9047244046	MR. ROBERT	INVESTOR	235	21720	94	1
32210	9045730541	JEFF & JANIC	INVESTOR	100	25920	16	1
32244	9047727072	UNIPROP	INVESTOR	783	86700	313	1
32233	9042410161	PROPERTY P	INVESTOR	100	6852	60	1
32223		MR. RODRIGO	INVESTOR	50	4200	10	1
32221	9047810441	CLAYTON HO	INVESTOR	1137	120000	455	1
32217	9047333730	BEAUCLERC	INVESTOR	265	40608	106	1
32219	9047659512	ULTIMATE INS	INVESTOR	60	15000	49	1

Attach To
Pg. 1 Here

CNTY	PWS ID	TYPE	SOURCE	MAILING NAME	STREET	CITY	STATE
16	2160125	COMMUNITY	GROUND	ATL BCH: BUCCANEER WS	1200 SANDPIP	ATLANTIC BEACH	FL
16	2160198	COMMUNITY	GROUND	GRAZING MEADOWS/CIRCLE	9539 103RD S	JACKSONVILLE	FL
16	2160223	COMMUNITY	GROUND	TAYLORS MHP	3522 COLJEA	JACKSONVILLE	FL
16	2160254	COMMUNITY	GROUND	DANIEL MEMORIAL	3725 BELFOR	JACKSONVILLE	FL
16	2160386	COMMUNITY	GROUND	SPANISH OAK APARTMENTS	7557 ARLINGT	JACKSONVILLE	FL
16	2160390	COMMUNITY		CRYSTAL SPRINGS ESTATE	500 SOUTH C	JACKSONVILLE	FL
16	2160563	COMMUNITY	GROUND	JACKSONVILLE BEACH WTP	2500 PULLIAN	JACKSONVILLE	FL
16	2160200	COMMUNITY	GROUND	ATLANTIC BEACH WATER SY	485 11TH STR	ATLANTIC BEACH	FL
16	2160442	COMMUNITY	GROUND	COLE'S MHP	10700 NORMA	JACKSONVILLE	FL
16	2160053	COMMUNITY	GROUND	BALDWIN WATER SYSTEM	10 US 90 WES	BALDWIN	FL
16	2160206	COMMUNITY	GROUND	NEPTUNE BEACH	1019 5TH AVE	NEPTUNE BEACH	FL
16	2160601	COMMUNITY	GROUND	JUSTISS TRAILER PARK	6414 YUKON	JACKSONVILLE	FL
16	2160735	COMMUNITY	GROUND	JEA: MAYPORT WTP	1459 JULIA ST	JACKSONVILLE	FL
16	2161327	COMMUNITY	GROUND	JEA: NORTH GRID	21 WEST CHU	JACKSONVILLE	FL
16	2161328	COMMUNITY	GROUND	JEA: SOUTH GRID	102 N. KERNA	JACKSONVILLE	FL

Attach To Pg 4 Here

ZIP	PHONE	OWNER	OWNER TYPE	POP SERVED	DESIGN CAP	SRVC CONNEC	#PLANTS
32233	9042475887	CITY OF ATLA	INVESTOR	10936	2120000	2200	2
32210	9047713974	WALLACE AN	INVESTOR	200	28800	78	1
32221	9047833294	MR. GLENN T	INVESTOR	105	22570	43	1
32216	9047371677	DANIEL MEM	INVESTOR	150	57600	16	1
32211	9047211257	1ST COAST F	INVESTOR	475	48696	190	1
32221	9047832460	AUGUST PAR	INVESTOR	502	99000	201	1
32250	9042476216	CITY OF JACK	MUNICIPALIT	20267	4737600	9404	2
32233	9042475830	CITY OF ATLA	MUNICIPALIT	14390	6070000	4662	2
32221	9047810876	COLE CONST	INVESTOR	120	60000	48	1
32234	9042669055	CITY OF BALD	MUNICIPALIT	1540	1200000	650	1
32266	9042702419	CITY OF NEPT	MUNICIPALIT	7500	2800000	3446	1
32230	9047726080	MRS. JUSTISS	INVESTOR	200	10940	63	1
32228	9046300905	JEA WATER &	MUNICIPALIT	2270	192000	548	1
32225	9046656248	JEA WATER &	MUNICIPALIT	420989	119126400	140280	2161327
32225	9046654553	JEA WATER &	MUNICIPALIT	396461	138207460	113274	2161328

JEA North Grid
JEA South Grid

Attach to Fig 3 [illegible]

Reference 21

United Water Florida (UWF):

PLANT	Well #	WQ#	ADDRESS	LAT (N) ***	LONG (W) ***	CASING DIA (IN) ***	TOTAL DEPTH(FT) ***	PUMPAGE GPM ***	# CONNECTIONS*
San Jose	1		7128 Balboa Road **	301445	813720	8	1312	1100	
	2		7128 Balboa Road **	301449	813723	16	1066	2800	4383
	3		7128 Balboa Road **	301446	813718	20	1300	2850	
Royal Lakes	1		8509 Western Way **	301244	813331	12	1170	1400	
	2		8509 Western Way **	301244	813333	12	1100	1700	2696
	3		6195 Lake Lugano Drive **	301244	813344	20	1200	2000	
Lake Forest	1			302339	814042	8	1101	900	840
Magnolia Gardens	1			302244	814215	8	1047	809	701
Arlington	1			302046	813555	8	1000	1100	
	2			302053	813510	8	1203	1200	
	3			302105	813404	10	1301	1500	6925
	4			302203	813614	8	1025	1400	
	5			301959	813417	8	1150	700	
	6			301956	813420	8	1150	1200	
Monnument Road	1		1258 Monument Road ****						
	2		1258 Monument Road ****						
Queen Akers	1		758 St. Johns Bluff ****						
Hyde Grove	1			301718	814529	8			359
Jacksonvile Heights	1			301523	814437	10	1203	1200	
	2			301445	814613	8	500	100	3671
	3			301423	814605	10	1149	1200	
Forest Brook	1			301433	814404	6	672	300	191
Venetia Terrace	1			301415	814300	6	833	500	245
Ortega Hills	1			301306	814239	10	956	270	449
	2			301304	814239	10	800	680	

* Fax received from Gordon Grimes (UWF) 7/10/01.
** Phone conversation with Tom Griffis (UWF) and Sandra Dowling (Dynamac) 7/10/01.
*** Fax received from April Roughton (St. John's River Water Management District) 7/16/01.
**** Phone conversation with T. Griffis (UWF) and P. Taylor (Weston) 7/17/01.

U.S. Census Bureau

State and County *QuickFacts*

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Duval County, Florida

Florida counties - view map

Duval County Go

Select a state
USA QuickFacts

Locate a county by place name

Follow the link for definition and source information.

Browse more data sets for Duval County, Florida

People QuickFacts	Duval County	Florida
Population, 2001 estimate	792,434	16,396,515
Population percent change, April 1, 2000-July 1, 2001	1.7%	2.6%
Population, 2000	778,879	15,982,378
Population, percent change, 1990 to 2000	15.7%	23.5%
Persons under 5 years old, percent, 2000	7.2%	5.9%
Persons under 18 years old, percent, 2000	26.3%	22.8%
Persons 65 years old and over, percent, 2000	10.5%	17.6%
Female persons, percent, 2000	51.5%	51.2%
White persons, percent, 2000 (a)	65.8%	78.0%
Black or African American persons, percent, 2000 (a)	27.8%	14.6%
American Indian and Alaska Native persons, percent, 2000 (a)	0.3%	0.3%
Asian persons, percent, 2000 (a)	2.7%	1.7%
Native Hawaiian and Other Pacific Islander, percent, 2000 (a)	0.1%	0.1%
Persons reporting some other race, percent, 2000 (a)	1.3%	3.0%
Persons reporting two or more races, percent, 2000	2.0%	2.4%
Persons of Hispanic or Latino origin, percent, 2000 (b)	4.1%	16.8%
White persons, not of Hispanic/Latino origin, percent, 2000	63.5%	65.4%
Living in same house in 1995 and 2000, pct age 5+, 2000	48.9%	48.9%
Foreign born persons, percent, 2000	5.9%	16.7%
Language other than English spoken at home, pct age 5+, 2000	9.5%	23.1%
High school graduates, percent of persons age 25+, 2000	82.7%	79.9%
Bachelor's degree or higher, pct of persons age 25+, 2000	21.9%	22.3%
Persons with a disability, age 5+, 2000	149,290	3,274,566
Mean travel time to work, workers age 16+ (minutes), 2000	25.2	26.2
Housing units, 2000	329,778	7,302,947
Homeownership rate, 2000	63.1%	70.1%
Housing units in multi-unit structures, percent, 2000	27.7%	29.9%
Median value of owner-occupied housing units, 2000	$89,600	$105,500
Households, 2000	303,747	6,337,929
Persons per household, 2000	2.51	2.46

	Median household money income, 1999	$40,703	$38,81(
	Per capita money income, 1999	$20,753	$21,55/
	Persons below poverty, percent, 1999	11.9%	12.5%

ST. JOHNS RIVER ALLIANCE

St. Johns River
An American Heritage River

Nature's Mystery, Florida's History

[Adventure] [Nature] [Culture] [History]

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Adventure

Along the St. Johns, a river adventure awaits, offering countless recreational opportunities. Fish, swim, kayak, hike or horseback ride - the St. Johns River is a getaway of outdoor splendor.

Chart your own course for eco-adventure and explore the magnificence of the river aboard a luxury houseboat in Deleon Springs State Park.

Anglers of all varieties will find themselves right at home along the river once dubbed by early tourists as the "Nile of America." Cast a line from the banks of the water or venture out on your own aboard one of the many possible boat rentals. Located a mere 160 miles from the ocean, tides and winds sometimes bring salt water sport fish such as tarpon and redfish to Lake Monroe. Or why not try your luck with the ever-popular largemouth bass? Nationally sponsored professional bass tournaments bring in hundreds of sportsmen to the basin. Whether a novice or tournament level angler the waterways of the St. Johns River provide the backdrop to the fishing getaway you've been dreaming of.

For the true pioneer these glassy waters are still a challenging frontier. Cave diving in the heart of the Ocala National Forest is the adventure of a lifetime. Alexander Springs is the place where divers can descend 27 feet below to hidden realms of white sand and limestone walls.

If you prefer the quieter side of adventure hiking, bicycling, horseback riding and bird watching may be just what you are looking for. Multitudes of trails along the St. Johns River offer

Topographical Facts

- The St. Johns River is the longest river in Florida stretching 310 miles from headwaters to mouth. It is one of the few rivers in the western hemisphere that flows north.
- The land area that drains into a water body is called a drainage basin — also called a watershed. The St. Johns is divided into three main drainage basins: Upper, Middle, and Lower.
- Because the river flows north, the upper basin is the area to the south that forms its marshy headwaters in Indian River and Brevard counties. The middle basin is the area in central Florida where the river widens, forming lakes Harney, Jesup, Monroe and George. The lower basin is the area in northeast Florida from Putnam County to the river's mouth in Duval County, where the river empties into the Atlantic Ocean.
- The width of the river varies. It is a flat marsh at its headwaters and averages about two miles in width between Palatka and Jacksonville. It widens to form large lakes in central Florida.
- The total drop of the river from its source in marshes south of Melbourne to its mouth in the Atlantic near Jacksonville is less than 30 feet, or about one inch per mile, making it one of the "laziest" rivers in the world.
- Because the river flows slowly, it is difficult for the river current to flush pollutants.
- Major pollution sources include discharges from wastewater treatment plants and storm water runoff from urban and agricultural areas. This runoff carries pesticides, fertilizers, and other pollutants into canals, ditches, and streams that lead to the river. River pollution is concentrated around urban areas.
- Salt water enters the river at its mouth in Jacksonville. In periods of low water, tides may cause a reverse flow as far south as Lake Monroe — 161 miles upstream from the river's mouth.
- Major tributaries, or smaller streams and rivers that flow into the St. Johns River include the Wekiva River, the Econlockhatchee River, and the Ocklawaha River.
- The St. Johns River is an ancient intracoastal lagoon system. As sea levels dropped, barrier islands became an obstacle that prevented water from flowing east to the ocean. The water collected in the flat valley and slowly meandered northward, forming the St. Johns River.

U.S. FISH AND WILDLIFE SERVICE
DIVISION OF ENDANGERED SPECIES

SPECIES ACCOUNTS

Source: *Endangered and Threatened Species of the Southeastern United States (The Red Book)* FWS Region 4 -- As of 8/93

WEST INDIAN MANATEE

Trichechus manatus

FAMILY: Trichechidae

STATUS: Endangered, *Federal Register*, March 11, 1967, June 2, 1970

DESCRIPTION: The West Indian Manatee is a large gray or brown aquatic mammal. Adults average about 10 feet long and weigh 1,000 pounds. They have no hindlimbs, and their forelimbs are modified as flippers. Manatee tails are flattened horizontally and rounded. Their body is covered with sparse hairs and their muzzles with stiff whiskers. Sexes are distinguished by the position of the genital openings and presence or absence of mammary glands. Manatees will consume any aquatic vegetation available to them and sometimes even shoreline vegetation. Although primarily herbivorous, they will occasionally feed on fish. Manatees may spend about 5 hours a day feeding, and may consume 4 to 9 percent of their body weight a day.

REPRODUCTION AND DEVELOPMENT: Observations of mating herds indicate that females mate with a number of males during their 2- to 4-week estrus period, and then they go through a pregnancy estimated to last 12 to 14 months (O'Shea 1992). Births occur during all months of the year with a slight drop during winter months. Manatee cows usually bear a single calf, but 1.5 percent of births are twins. Calves reach sexual maturity at 3 to 6 years of age. Mature females may give birth every 2 to 5 years. The only long-term, stable bond between manatees is that between a cow and her calf. Weaning generally occurs between 9 and 24 months of age, although a cow and calf may continue to associate with each other for several more years. There is little information on the life-time reproductive output of females, although they may live over 50 years.

RANGE AND POPULATION LEVEL: During the winter months, the United States' manatee population confines itself to the coastal waters of the southern half of peninsular Florida and to springs and warm water outfalls as far north as southeast Georgia. Manatees also winter in the St. Johns River near Blue Spring State Park. During summer months, they may migrate as far north as coastal Virginia on the east coast and the Louisiana coast on the Gulf of Mexico.

Manatee populations also exist outside the continental United States in coastal areas of the Caribbean and Central and South America. In Puerto Rico, manatees apparently occur around the southern and eastern end of the island and around nearby Vieques Island. Except for rare sightings, manatees seem to be absent from the Virgin Islands at present, but fossils have been found in middens on St. Croix.

The population of manatees in Florida has been estimated to be at least 1,865 individuals. There are an estimated 60 to 100 manatees in Puerto Rico. In the last decade, yearly mortality in Florida has averaged nearly 150 animals a year, double that of the preceding decade. The average proportion of first-year calves in the population is 10 percent with a range of 5 to 15 percent.

HABITAT: Manatees inhabit both salt and fresh water of sufficient depth (1.5 meters to usually less than 6 meters) throughout their range. They may be encountered in canals, rivers, estuarine habitats, saltwater bays,

and on occasion have been observed as much as 3.7 miles off the Florida Gulf coast. Between October and April, Florida manatees concentrate in areas of warmer water. When water temperatures drop below about 21 to 22 degrees Centigrade, they migrate to south Florida or form large aggregations in natural springs and industrial outfalls. Severe cold fronts have been known to kill manatees when the animals did not have access to warmwater refuges. During warmer months they appear to choose areas based on an adequate food supply, water depth, and proximity to fresh water. Manatees may not need fresh water but they are frequently observed drinking fresh water from hoses, sewage outfalls, and culverts. There is no evidence of any periodicity in manatee habitat use in Puerto Rico.

CRITICAL HABITAT: The following areas in Florida (exclusive of those existing manmade structures or settlements which are not necessary to the normal needs or survival of the species) are critical habitat for the manatee: Crystal River and its headwaters known as King's Bay, Citrus County; the Little Manatee River downstream from the U.S. Highway 301 bridge, Hillsborough County, the Little Manatee River downstream from the Lake Manatee Dam, Manatee County; the Myakka River downstream from Myakka River State Park, Sarasota and Charlotte Counties; the Peace River downstream from the Florida State Highway 760 bridge, DeSoto and Charlotte Counties; and Charlotte Harbor north of the Charlotte-Lee County line, Charlotte County; Caloosahatchee River downstream from the Florida State Highway 31 bridge, Lee County; all United States territorial waters adjoining the coast and islands of Lee County; all United States territorial waters adjoining the coast and islands and all connected bays, estuaries, and rivers from Gordon's Pass near Naples, Collier County, southward to and including Whitewater Bay, Monroe County; all waters of Card, Barnes, Blackwater, Little Blackwater, Manatee, and Buttonwood Sounds between Key Largo, Monroe County; and the mainland of Dade County; Biscayne Bay, and all adjoining and connected lakes, rivers, canals, waterways from the southern tip of Key Biscayne northward to and including Maule Lake, Dade County; all of Lake Worth, from its northernmost point immediately south of the intersection of U.S. Highway 1 and Florida State Highway A1A southward to its southernmost point immediately north of the town of Boynton Beach, Palm Beach County; the Loxahatchee River and its headwaters, Martin and West Palm Beach Counties; that section of the intracoastal waterway from the town of Sewalls Point, Martin County, to Jupiter Inlet, Palm Beach County; the entire section of water known as the Indian River, from its northernmost point immediately south of the intersection of U.S. Highway 1, and Florida State Highway 3, Volusia County, southward to its southernmost point near the town of Sewalls Point, Martin County; the entire inland section of water known as the Banana river and all waterways between the Indian and Banana rivers, Brevard County; the St. Johns River including Lake George, and including Blue Springs and Silver Glen Springs from their points of origin to their confluences with the St. Johns River; that section of the Intracoastal Waterway from its confluence with the St. Marys River on the Georgia-Florida border to the florida State Highway A1A bridge south of Coastal City, Nassau and Duval Counties.

REASONS FOR CURRENT STATUS: The manatee population was probably more abundant in the 18th or 19th century than today. Initial population decreases probably resulted from overharvesting for meat, oil, and leather. Today, hunting is prohibited and is not considered a problem, although there is an occasional incidence of poaching. Heavy mortality does occur, however, from accidental collisions with boats and barges, and from canal lock operations.

Manatee population trends are poorly known, but deaths have increased steadily (6.1 percent a year, exponential regression, 1976 to 1991). Mortalities from collisions with watercraft are up 10.3 percent a year from 21 percent of all deaths in 1976 to 1980 to 29 percent in 1986 to 1991. Deaths of dependent calves are up 12 percent a year from 14 to 24 percent of all deaths. The combination of high mortality rates and low reproductive rates have led to serious doubts about the species' ability to survive in the United States.

Another closely related factor in the decline has been the loss of suitable habitat through incompatible coastal development, particularly destruction of seagrass beds by boating facilities. In Puerto Rico, the primary cause of manatee mortality seems to be from entanglement in gill nets. Collisions with boats and illegal killing of manatees for food may also be affecting the Puerto Rican population to some extent, but supporting data are limited.

MANAGEMENT AND PROTECTION: Based on revised recovery plan (1989) recommendations, the primary objective in the recovery of the Florida population of the West Indian manatee is to reestablish and maintain optimum sustainable populations in natural habitats throughout the manatee's historic range. To accomplish this primary objective there are several sub-objectives. They are:

1. Minimize human-caused injuries and mortalities to manatees. Rescue and rehabilitate sick, injured, or orphaned manatees. Minimize mortality from boat and barge collisions, water control structures, and poaching. Evaluate effectiveness of current and future regulations and enforcement efforts. Conduct programs to inform and educate the public and develop bilateral and multilateral agreements with other countries for manatee conservation and research.

2. Minimize alteration, degradation, and destruction of habitat used by manatees and monitor its status. (Adverse habitat alteration may result from human use of water resources and industrial and residential .development.) Evaluate potential hazards such as coastal zone development, outer continental shelf oil and gas development, toxicants, dredging, siltation, and power plant failures. Identify, protect, and monitor areas of special significance to manatees and enhance habitats used by manatees.

3. Minimize harassment of manatees from boat and barge traffic, fishing, diving, and swimming.

4. Determine and monitor status of manatee population and determine aspects of life history and ecology.

5. Coordinate implementation of recovery activities, monitor and evaluate progress, and periodically update and revise recovery plan.

A recovery plan developed specifically for the manatee population in Puerto Rico indicates three primary objectives for recovery. The first objective is to identify, assess, and reduce human-related mortality, especially that related to gill net entanglement. The second objective is to identify and minimize alteration, degradation, and destruction of habitats important to the survival and recovery of the Puerto Rico manatee population. The third objective is to develop the criteria and biological information necessary to determine whether and/or when to delist or downlist (reclassify to threatened) the Puerto Rican population of manatees.

REFERENCES:

Hartman, D. S. 1979a. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. Am. Soc. of Mammal. Spec. Publ. 5. 153 pp.

Hartman, D. S. 1979b. West Indian Manatee. Pages 27-39 *in* J.N. Layane, Threatened. Rare and Endangered Biota of Florida, Vol. 1, Mammals. University Presses of Florida, Gainesville.

O'Shea, T. J., B. B. Ackerman, and H.F. Percival (eds.). 1992. Interim report of the technical workshop on manatee population biology. Manatee Population Research Report No. 10. Florida Cooperative Fish and Wildlife Research Unit, Univ. of Florida, Gainesville, FL. 83 pp.

Powell, J. A. and G. B. Rathbun. 1984. Distribution and abundance of manatees along the northern coast of the Gulf of Mexico. Northeast Gulf Science. Vol. 7. No. 1, p. 1-28.

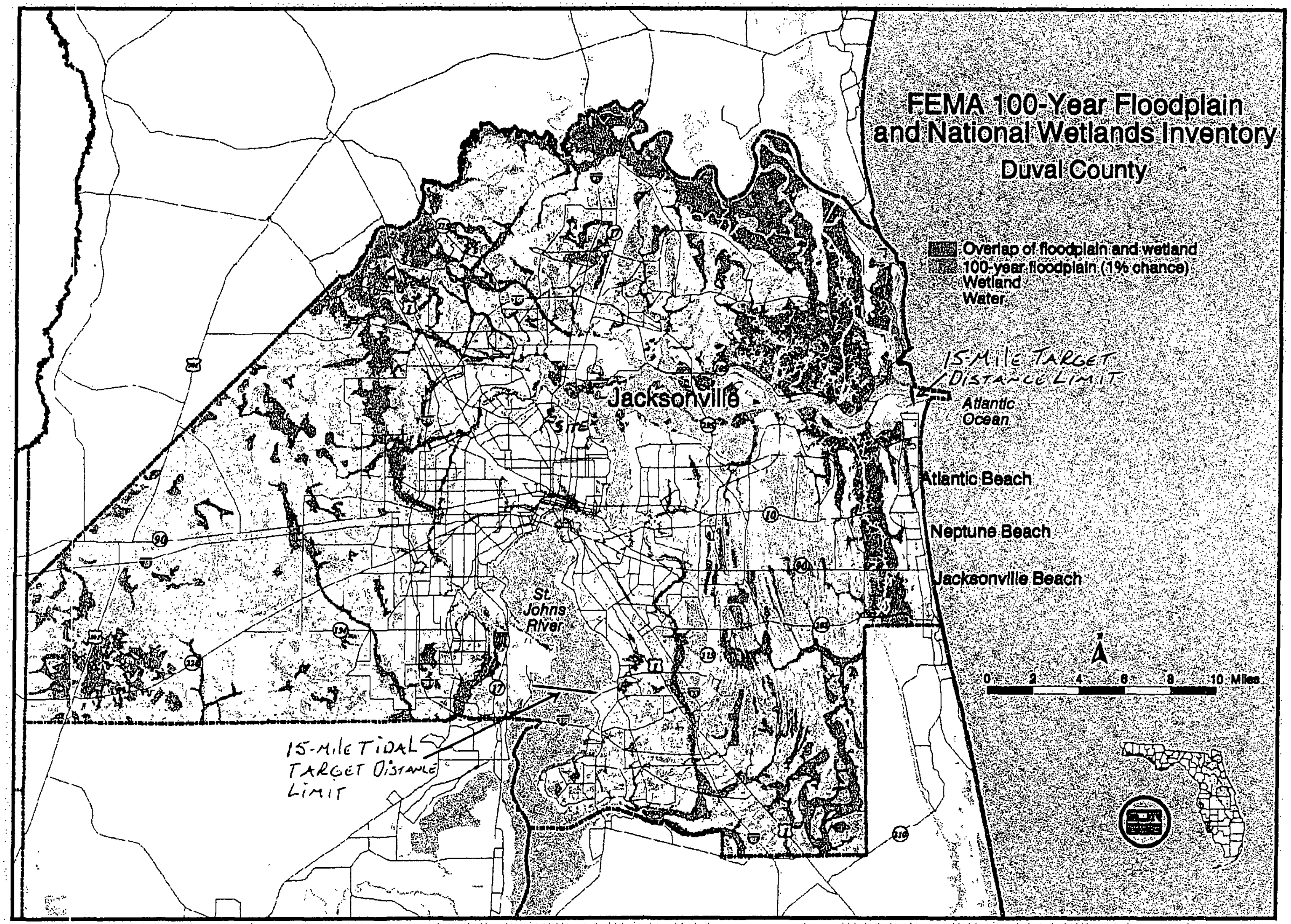
**U. S. Fish and Wildlife Service. 1989. Florida Manatee Recovery Plan. U.S. Fish and Wildlife Service, Atlanta, Georgia. 98 pp.

**U. S. Fish and Wildlife Service. 1986. Recovery Plan for the Puerto Rico Population of the West Indian (Antillean) Manatee. U.S. Fish and Wildlife Service, Atlanta, Georgia. 35 pp.

For more information please contact:

U. S. Fish and Wildlife Service
6620 Southpoint Drive South
Suite 310
Jacksonville, Florida 32216-0912

Telephone: (904)232-2580



Reference 25

FEMA 100-Year Floodplain and National Wetlands Inventory

Comprehensive Plan Element Reference(s)
The information provided on this map may be useful for the following plan elements: future land use plan; general sanitary sewer, solid waste, drainage, potable water, and natural groundwater aquifer recharge; conservation; recreation and open space; and coastal management.

Map Information
The map displays the 100-year floodplain based on data from the Federal Emergency Management Agency (FEMA) flood insurance rate maps. Floodplains are delineated according to the estimated statistical frequency of flooding (e.g., the 100-year flood). The 100-year floodplain, commonly delineated for regulatory purposes, defines an area that, statistically, has a 1% chance of being inundated in any given year. However, in reality, 100-year floods could occur in consecutive years or, on the other hand, a 100-year flood need not occur within a 100-year period.

The wetland areas shown are based on data from the U.S. Fish and Wildlife Service's National Wetlands Inventory. The map also shows where the 100-year floodplain areas and wetlands overlap.

Local governments have the primary responsibility for regulating land uses in floodplains and flood prone areas. Local measures include land use planning, construction standards, stormwater management facilities, and flood control structures.

Water management districts complement local efforts by implementing regional flood protection projects and programs. Programs include environmental resource permitting, land acquisition, floodplain restoration, and technical assistance.

Flooding is a natural phenomenon in Florida, commonly occurring along streams, rivers, lakes, and coastal areas. Floodplains — the low-lying lands that are subject to flooding — provide a variety of benefits, including water storage, filtration, erosion control, habitat, and recreation. Flooding becomes a problem when people, property, and roads are adversely affected.

Floodplains and wetlands are displayed together on this map to illustrate the overlap of the two data sets and to show potential discrepancies. In almost all cases, a wetland is a floodplain, but floodplains are often not wetlands.

Map on following page.

USGS 02246500 ST. JOHNS RIVER AT JACKSONVILLE, FLA.

Duval County, Florida
Hydrologic Unit Code 03080103
Latitude 30°19'16", Longitude 81°39'54" NAD27
Drainage area 8,850.00 square miles

1972	4,700

Year	Annual mean streamflow, in ft^3/s
1973	3,902

Year	Annual mean streamflow, in ft^3/s
2000	3,696

POPULATION WORKSHEET	
Florida Smelting Company/Buffalo Avenue, Jacksonville, Duval County, Florida **FLD000407555**	
Population Radius	**Population**
0.25 Mile	163
0.50 Mile	1,654
1 Mile	5,713
2 Mile	24,075
3 Mile	66,063
4 Mile	114,266
Population Ring*	**Population**
0 to 0.25 Mile	163
0.25 to 0.5 Mile	1491
0.5 to 1 Mile	4059
1 to 2 Mile	18362
2 to 3 Mile	41988
3 to 4 Mile	48203

*Population rings were determined by subtracting out the previous area's value from the current population value.

Reference: LandView V

Name: Allyson Warrington

Signature: Allyson Warrington

TN&Associates, Inc.
840 Kennesaw Avenue, Suite 7
Marietta, GA 30060
(678) 355-5550

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	0.25
— or —			
deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	◉ North ○ South	◉ West ○ East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census Block points located within or touching the circle defined by the radius)

Total population:	163	Block count:	10
Housing Units:	82	Area within radius:	0.2 sq. mi.

White alone:	79
Black or African American alone:	72
American Indian and Alaska Native alone:	4
Asian alone:	0
Native Hawaiian and Other Pacific Islander alone:	0
Some other race alone:	7
Two or more races:	1
Hispanic or Latino:	8

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	0.5
— or —			
deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	(●) North ( ) South	(●) West ( ) East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census - Block points located within or touching the circle defined by the radius)

Total population: 1,654 | Block count: 43

Housing Units: 747 | Area within radius: 0.8 sq. mi.

White alone:	833
Black or African American alone:	781
American Indian and Alaska Native alone:	15
Asian alone:	5
Native Hawaiian and Other Pacific Islander alone:	0
Some other race alone:	11
Two or more races:	9
Hispanic or Latino:	40

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	1.0
or deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	(•) North ( ) South	(•) West ( ) East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census Block points located within or touching the circle defined by the radius)

Total population:	5,713	Block count:	149
Housing Units:	2,616	Area within radius:	3.1 sq. mi.

White alone:	2619
Black or African American alone:	2931
American Indian and Alaska Native alone:	22
Asian alone:	43
Native Hawaiian and Other Pacific Islander alone:	1
Some other race alone:	24
Two or more races:	73
Hispanic or Latino:	101

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	2.0
— or —			
deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	◉ North ○ South	◉ West ○ East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census - Block points located within or touching the circle defined by the radius)

Total population: 24,075 Block count: 608

Housing Units: 10,675 Area within radius: 12.6 sq. mi.

White alone:	7337
Black or African American alone:	16103
American Indian and Alaska Native alone:	78
Asian alone:	164
Native Hawaiian and Other Pacific Islander alone:	12
Some other race alone:	114
Two or more races:	267
Hispanic or Latino:	413

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	3.0
— or —			
deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	◉ North ○ South	◉ West ○ East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census Block units located within or touching the circle defined by the radius)

Total population:	66,063	Block count:	1,275	
Housing Units:	30,195	Area within radius:	28.3	sq. mi.

White alone:	17459
Black or African American alone:	46511
American Indian and Alaska Native alone:	190
Asian alone:	515
Native Hawaiian and Other Pacific Islander alone:	36
Some other race alone:	467
Two or more races:	885
Hispanic or Latino:	1396

LandView Census 2000 Population Estimator

Instructions for using this estimator | Home

Enter Location and Radius

	Latitude	Longitude	Radius (miles)
Decimal degrees	30.377222	81.640833	4.0
or deg-min-sec	30 22 37	81 38 26	Calculate Population
hemisphere	(•) North ( ) South	(•) West ( ) East	

Clear all fields | Refresh Lat/Long from MARPLOT | Print this screen | Show this radius on map

Results (based on Census Block points located within or touching the circle defined by the radius)

Total population:	114,266	Block count:	2,256	
Housing Units:	50,683	Area within radius:	50.3	sq. mi.

White alone:	33660
Black or African American alone:	76988
American Indian and Alaska Native alone:	311
Asian alone:	914
Native Hawaiian and Other Pacific Islander alone:	63
Some other race alone:	840
Two or more races:	1490
Hispanic or Latino:	2502

U.S. EPA REGION IV

SDMS

Unscannable Material Target Sheet

DocID: 10762859 Site ID: FLN000402555

Site Name: Florida Smelting

Nature of Material:

Map:	☐	Computer Disks:	☐
Photos:	☐	CD-ROM:	☑
Blueprints:	☐	Oversized Report:	☐
Slides:	☐	Log Book:	☐

Other (describe): Analytical Data Sheets

Amount of material: ______

* Please contact the appropriate Records Center to view the material *